THE LOGIC OF COMPLEMENTARITY

IN SCIENCE AND THEOLOGY

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Summary

Niels Bohr intended his concept of complementarity to be a general principle of knowledge, and several writers, including Bohr himself, have suggested that it might be applicable to various problems in Christian theology. The purpose of this study is to examine the concept in detail and evaluate these suggestions. Bohr's philosophy is discussed, and the logic of his complementarity principle is mapped, first in atomic physics, and then in other fields of application. The views of Bohr's allies and critics are carefully considered. Previous theological applications are reviewed, and then a systematic attempt is made to apply the principle to a number of Christian doctrines as these are expounded in the theological literature. Questions of method are discussed throughout, and it is recognized that this is only one of many possible ways to tackle such a complex issue. The study concludes with an overall evaluation and suggestions for further research.

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Abbreviations of Journal Titles

Am.J.Phys.	American Journal of Physics
Ann.Phys.	Annalen der Physik
B.J.P.S.	British Journal for the Philosophy of Science
Bul.Atom.Sci.	Bulletin of the Atomic Scientists
Comptes Rendus	Comptes Rendus des Séances de l'Academie des Sciences (Paris)
I.J.A.L.	International Journal of American Linguistics
I.J.P.R.	International Journal for Philosophy of Religion
J.Chem.Soc.	Journal of the Chemical Society
J.Phil.	Journal of Philosophy
J.Phys.Rad.	Le Journal de Physique et le Radium
J.Rel.	Journal of Religion
J.Th.Biol.	Journal of Theoretical Biology
Naturwis.	Die Naturwissenschaften
Nuc.Phys.	Nuclear Physics
Nuo.Cim.	Il Nuovo Cimento
Phil.Phen.Res.	Philosophy and Phenomenological Research
Phil.Sci.	Philosophy of Science
Phys.Rev.	Physical Review
Proc.Arist.Soc.	Proceedings of the Aristotelian Society
Proc.Nat.Acad.Sci.	Proceedings of the National Academy of Sciences
Proc.Roy.Soc.London	Proceedings of the Royal Society of London
Prog.Th.Phys.	Progress of Theoretical Physics (Japan)
Rel.Stud.	Religious Studies
Rev.Mét.Mor.	Revue de Métaphysique et de Morale
Rev.Mod.Phys.	Revue of Modern Physics
Sci.Am.	Scientific American
Scot.J.Th.	Scottish Journal of Theology
Zeit.Natur.	Zeitschrift für Naturforschung
Zeit.Phys.	Zeitschrift für Physik

Abbreviations of Latin Works

Ambrose	De Fide	De Fide, ad Gratianum
	Enar.in Ps.	Enarrationes in Psalmos
Anselm	De Proc.Spir. Sanct.	De Processione Spiritus Sancti
Athanasius	De Decr.	De Decretis
	De Inc.	De Incarnatione Verbi Dei
	Ep.ad Serap.	Epistolae ad Serapionem
	Or.con.Ar.	Orationes contra Arianos
Aquinas	De Ver.	De Veritate Quaestiones Disputatae
	Sum.Theol.	Summa Theologica
	Sum.Con.Gen.	Summa Contra Gentiles
Athenagoras	Suppl.	Supplicatio
Augustine	Con.Maxim.	Contra Maximinum
	De Trin.	De Trinitate
	Enar.in Ps.	Enarrationes in Psalmos
	Enchir.	Enchiridion
	Ep.	Epistolae
	In Johan.	In Johannis Evangelium
	Sermo.	Sermones
Basil	Con.Eunom.	Contra Eunomium
	De Spir.Sanct.	De Spiritu Sancto
	Ep.	Epistolae
	Hom.	Homiliae
Calvin	Inst.	Institutio Christianae Religionis
Clement of Alexandria	Protrept.	Protrepticus
	Strom.	Stromateis
Cyprian	De Unit.Eccles.	De Unitate Ecclesiae
Cyril of Alexandria	Adv.Nest.	Adversus Nestorii Blasphemias
	Com.in Johan.	Commentarius in Johannem
	Ep.	Epistolae
	Schol.de Inc.	Scholia de Incarnatione Unigeniti
	Thes.	Thesaurus
Cyril of Jerusalem	Cat.	Catecheses
Didymus the Blind	De Trin.	De Trinitate
Dionysius the Areopagite	De Div.Nom.	De Divinis Nominibus
Epiphanius	Adv.Haer.Pan.	Adversus Haereses Panarium
	Expos.Fid.	Expositio Fidei
Gregory of Nazianzus	Ep.	Epistolae
	Or.(Orat.)	Orationes

Gregory of Nyssa	Ant.adv.Apol	Antirrheticus adversus Apollinarium
	Con.Eunom.	Contra Eunomium
	Non tres Dei	Quod non sint tres Dei
	Or.Cat.	Oratio Catechetica
Hilary	De Syn.	De Synodis
	De Trin.	De Trinitate
Hippolytus	Con.Noet.	Contra Noetum
	Ref.	Refutatio Omnium Haeresium
Irenaeus	Adv.Haer.	Adversus Haereses
John Chrysostom	In Quat.Laz.	In Quatriduarium Lazarum
John of Damascus	De Fid.Orth.	De Fide Orthodoxa
Leo the Great	Ep.	Epistolae
Leontius of Byzantium	Con.Nest.et Eut.	Contra Nestorianos et Eutychianos
Leontius of Jerusalem	Con.Nest.	Contra Nestorianos
Maximus the Confessor	Amb.Lib.	Ambiguorum Liber
	Disp.cum Pyr.	Disputatio cum Pyrrho
	Ep.	Epistolae
	Opusc.	Opuscula Theologica et Polemica ad Marinum
Novatian	De Trin.	De Trinitate
Origen	Com. in Johan.	Commentarius in Johannem
	Con.Cels.	Contra Celsum
	De Orat.	De Oratione
	De Princ.	De Principiis
	In Jer.Hom.	In Jeremiam Homiliae
Psuedo-Cyril	De Sac.Trin.	De Sacrosancta Trinitate
Richard of St. Victor	De Trin.	De Trinitate
Tertullian	Adv.Marc.	Adversus Marcionem
	Adv.Prax.	Adversus Praxean
	De Res.Car.	De Resurrectione Carnis
Theodore of Mopsuestia	De Inc.	De Incarnatione
	Hom.Cat.	Homiliae Catecheticae
Theodoret of Cyrus	Ep.	Epistolae
	Eran.	Eranistes
Victorinus	Adv.Ar.	Adversus Arianos
	De Gen.Verb.	De Generatione Verbi

The Logic of Complementarity in Science and Theology

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Preface

The scope of the following study is broad and, at the same time, narrow. It is broad in the obvious sense that it ranges over both science and theology; in fact, over a variety of special sciences and a variety of topics in Christian theology. Throughout, however, we are concerned with a single, common theme: the problem of the relationship of the parts to the whole or the relationship between different modes or levels of being, a problem which has long been of concern to philosophers and theologians (cf. the 'one' and the 'many') and has now risen afresh in modern science (especially in quantum physics and molecular biology). In other words, we are attempting a comparative study in the history of ideas, and the breadth of the investigation is made possible by the strict limitation to a particular theme.

This does not mean that other issues will not arise. We shall encounter a great many, but only in the context of the investigation at hand. Occasionally, tentative conclusions can be drawn on such issues (e.g. the relational character of attributes), but these conclusions can only be functions of the particular method being followed. If we imagine the world of ideas as a multi-dimensional space in which the history of ideas takes place, then the present study might be considered a 'trajectory' within this space. Its purpose is to probe the relations of the ideas to each other. The conclusions, then, are all of the type: "If this is true, then that follows, provided certain other conditions are satisfied."

It follows that our study is far from being definitive since a variety of other 'trajectories' could be executed, some 'intersecting' the present one and others 'parallel' or even 'skew'. However, my hope is that it will be definitive in the sense that this particular trajectory will demonstrate that there are underlying issues common to science and theology, including not only the principal theme of modality but also subsidiary ones such as the use of models and metaphors. Moreover, it should demonstrate that there are also other issues, such as the nature of history, that are more prominent in theology than in the sciences. In other words, the chosen trajectory serves to illustrate the general relationship between science and theology and provides an 'hypothesis' about this relationship which could be corroborated by other trajectories or studies undertaken in the same spirit.

Our investigation is limited not only by the particular theme chosen but also by a particular starting-point and a particular method. The basis of the investigation is the 'principle of complementarity' first developed by Niels Bohr to account for the relation of atomic particles to the stable states of the atoms to which they belong. Accordingly, the first half of our study is an attempt to establish the precise content of 'complementarity' as Bohr himself understood it. In particular, we shall look at Bohr's philosophy as a whole and the role that complementarity played within it (chapter 1), the precise significance of complementarity (for Bohr) in quantum physics (chapter 2), its application to other sciences (chapter 3), and, finally, the uses and criticisms of the idea by other scientists and philosophers (chapters 4 and 5). The principal results will be: (a) an eleven-point definition of the complementarity relation itself, and (b) three further 'principles' which are required to develop a hierarchy of complementarities in the various sciences. This is the starting-point for our study as a whole.

The method used for completing the 'trajectory' into theology is roughly hypothetico-deductive. Granted that problems involving modality occur in theology, and given complementarity as a particular model for handling similar problems in science, there arises the possibility of testing complementarity as a conceptual tool in the theological field. Such a 'test' would not be a severe one, however, since it is not claimed that all theological problems are susceptible to complementarity, but only that some are. Hence our 'hypothesis' would be verifiable but not strictly falsifiable.[1] But the test could be tightened up, as it were, if some finite group of theological doctrines could be identified and the claim were made that complementarity must apply to all members of that group.

Accordingly, the application to theology takes place in two stages. First, a preliminary survey is made of previous suggestions for applications of complementarity to theology (chapter 6). Some of these must be discarded out-of-hand, but others remain as 'candidates' for complementarity,

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1. J.W.N.Watkins points out that statements of the form, "there exists a...", are non-falsifiable, just as those of the form, "for every...", are non-verifiable; see his "Confirmable and Influential Metaphysics", Mind 67, 1958, pp. 344ff.

at least, as far as the preliminary survey is concerned. Now, it turns out that all of these 'candidates' share a common element (their 'revelational' structure) and, moreover, that this element bears a prima facie resemblance to one of the eleven features of complementarity (the 'pointing' relationship). Therefore, we choose the complete group of theological doctrines sharing this feature as the testing-ground for our hypothesis. Fortunately there are no more than six or seven doctrines in the group.

Once the testing-ground has been established, the second stage of the application to theology begins (chapters 7 to 11). Here complementarity is used as a format for the exposition of the various doctrines in two ways: (a) the eleven-point definition of complementarity is used as a format for the exposition of the individual doctrines, and (b) the three principles pertaining to the hierarchy of complementarities are used to investigate the relationship between the doctrines. The result of (b) is an overall hierarchy involving both science and theology, i.e. nature, man and God. Of course, the hierarchy itself is not new, but the novel feature here is that it is constructed systematically with a minimum of basic postulates.

The reference here to 'verification' should not be taken too seriously; it is intended as a guide to procedure, not as a criterion for truthfulness. In principle, the opposite direction of inquiry (the reverse 'trajectory') could just as well have been followed; the doctrines of Christian theology could have been taken as the starting-point and the natural sciences as the testing-ground, although this would have been far more difficult in practice due to the less formalized nature of theology. The possible value of complementarity should rather be judged on the basis of its comprehensiveness as an integrating principle, its relative precision of formulation, and its fruitfulness in suggesting new insights, unforseen relationships, and possibilities for new lines of research (chapter 12). Even though it is only one of many possible trajectories in the world of ideas, it will prove, I hope, to be a uniquely fortunate one.

The procedure of using complementarity as a format in theology is, of course, subject to all the dangers of extrapolating and imposing categories from one field of study onto another.[2] Therefore, great care must be taken not to force a fit but to allow the theological material to assume its own characteristic form under the pressure of the imposed format. This is a question of execution, however, not of method, and each theological doctrine will offer its own peculiar form of 'resistance' which will be a matter of great interest in itself.

One result of this resistance is that the definitive terms of complementarity will be semantically displaced as they are applied to each new problem, and this must be allowed if arbitrariness is to be mimimized. In fact, the same holds true for the application of complementarity to sciences other than atomic physics, hence the value of studying Bohr's applications to fields like biology and psychology before looking at the problems of theology. In other words,

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2. See T.F.Torrance, Theological Science, London, 1969, pp.284f.

room for semantic displacement is built into the logic of complementarity itself; it is not merely invented for the sake of theology. The overall result, then, is that complementarity becomes a purely formal principle, a theme which allows for variations, and it should not be identified too closely with atomic physics. In fact, Bohr may have derived his basic insights from his thinking about biology and psychology. The development and interpretation of quantum mechanics merely provided the occasion, as it were, for his formalizing the principle in fairly rigorous terms.

Nonetheless, the prestige of complementarity is inevitably bound up with that of 'orthodox' quantum mechanics, and it is no secret that the latter is being seriously questioned today by a number of both physicists and philosophers. Of course this situation is not at all new; the basic principles of quantum theory have been challenged from the start even by many of the physicists who pioneered in its early development. It is not that quantum mechanics has been refuted or falsified in any way. To the contrary, the mathematical formalism is both elegant and fully consistent, and its predictions have been verified far beyond the experimental range upon which it was based. The difficulty lies with the interpretation of the formalism and particularly with the Heisenberg 'uncertainty principle', Bohr's 'principle of complementarity', and the problem of 'completeness' raised by Einstein. In view of this controversy, we cannot possibly regard complementarity as a sure result of the exact sciences, now to be imported into theology in order to provide support for orthodox Christianity. Our concern is primarily with the comparative history of ideas and the quest for underlying issues, and it has considerable value in itself independent of the popularity of the particular ideas studied in either science or theology. However, to be honest, I would not have taken such an interest in Bohr's ideas if I did not believe that they were viable at the very least. Moreover, I could not sustain my thesis for long if I did not try to present these ideas in their best light. In this sense I must assume the role of an apologist for Bohr.

The results of the apologetic approach are worth noting. For one thing, I find that Bohr's ideas fit together in a coherent way. I don't think this has been sufficiently appreciated before. Although some extremely valuable studies of Bohr's ideas have been done recently, I don't think that they have taken sufficient regard for the integrity of Bohr's thought *as a whole*.[3] They have invariably isolated one or two elements and treated the others as being arbitrary. My own conclusion is that Bohr's ideas stand or fall together; there is an overall logic to his thinking, and it is in this context that complementarity should be evaluated.

A second result is the conclusion that Bohr has been largely misunderstood by his critics. There are two reasons for this: one is the subtlety of his ideas compounded with the impenetrability of his prose style, and the other is the confusion caused by his many followers and allies. I was

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3. The recent study by E.Scheibe (*The Logical Analysis of Quantum Mechanics*, Oxford, 1973, ch.1) comes closest to the ideal, but it is confined to Bohr's thoughts about atomic physics and does not do justice to the principle of complementarity itself.

surprised to find that none of Bohr's supposed allies really represented his thinking as a whole. The results have been particularly damaging for our understanding of the principle of complementarity. The literature contains a variety of different versions, and critics have frequently mistaken these for Bohr's original intentions.

Finally, I have come to the conclusion that the present difficulties in quantum theory are not caused by the contributions made by Bohr; if anything, they are due to the neglect of his insights.[4] Bohr was basically an intuitive thinker who stressed the physical principles of quantum mechanics whereas the present conceptual difficulties stem from a misplaced emphasis on the formal, mathematical side (e.g. the 'collapse' of the 'state vector'). It might be hoped, therefore, that a renewed interest in Bohr's work as a whole would lead to a clarification at the foundations of physics as well as theology.

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4. "Here it must be recalled that there is no single formulation of quantum mechanics based entirely and consistently on the principles proposed by Bohr." E.Scheibe, *op.cit.*, p.4.

Part I

The Logic of Complementarity in Science

Chapter 1

The Philosophy of Niels Bohr

> The notion of complementarity...simply stresses the character of objective description, independent of subjective judgement, in any field of experience where unambiguous communication essentially involves regard to the circumstances in which evidence is obtained. N. Bohr, Essays: 1958-1963, p.60.

Niels Bohr is one of the most quoted, yet least understood, of the pioneers of modern physics. Various interpretations of his thought will be considered in chapters 4 and 5 after we have thoroughly examined Bohr's philosophy in its own right, but it would be wise first to consider the man and his background in order to see why he is so frequently misunderstood and to establish some points of method.

1.1 General Characteristics:

Perhaps the most striking characteristic of Bohr's writings is their ponderous quality of terseness. We know from his collaborators that Bohr continually struggled with language to improve the formulation of his ideas.[1] The result was a discontinuous series of aphorisms which appear to be loaded with meaning and yet are often difficult to interpret from the context.[2] A comparison of his famous essay "Light and Life" which first appeared in 1933[3] with a later revised version[4] shows the attention Bohr paid to minute detail. Yet one finds the revised version, if anything, more enigmatic than the original.

This opaque prose style helps to account for the variety of interpretations of Bohr's philosophy. On the other hand, the care with which Bohr expressed his ideas suggests that a comparative study of his writings might enable one to decipher his aphoristic code. It is surprising that no systematic study of this kind has yet been published.[5] He wrote not more than thirty essays of philosophical interest, and all of these have been published in English.[6] More than half of these essays have been reprinted in three collective volumes[7] and are readily available. The problem was that while Bohr was alive he was regarded as more of a symbol, to be blindly followed or else senselessly maligned, than a serious thinker in his own right. Like Einstein, he has been claimed as the champion of everything from Kantian idealism to logical positivism, dialectical materialism and naive realism,[8] and few people have been willing to listen to the man himself to hear what he was trying to say. Too often one finds writers expounding the ideas of Bohr but quoting passages from Heisenberg or von Weizsäcker or Jordan.[9] The procedure in this study, therefore, will be to examine Bohr's writings thoroughly before turning to those of his followers.

Another reason for the confusion about Bohr's ideas is his dialectical style of writing. One might even call his style dialogical since Bohr always hammered out his ideas in conversation with his friends before committing them to writing.[10] He particularly valued the opinions of those who were critical and, above all, the continual battle of "thought experiments" with Albert Einstein.[11] This continual dialogue is reflected in the informal use of paradox in Bohr's writings. When confronted with an apparent contradiction in his thought, he never sought to harmonize the conflicting elements but would always try to accentuate the contrast as much as possible in the hope that a new coherence would emerge.[12] At times he seems overtly to contradict himself, yet the extreme care he took with all his published articles suggests that the paradox is intenional and the contradiction is only apparent. Bohr's critics often take advantage of the ambiguity,[13] but our presupposition here will be that Bohr is at all times consistent with himself and that apparently contradictory statements should be weighed together with proper consideration for the natural changes in emphasis over the years. This method does, in fact, lead to a coherent picture of Bohr's philosophy.

1.2 Philosophical Background:

We should look into the possible influences on Bohr of the various philosophical trends that provided the background for the development of twentieth-century physics.[14] The greatest influence on Bohr came through the discussion groups in his father's home in Copenhagen.[15] Christian Bohr was a biologist with an intense interest in the vitalist-mechanist debate concerning the nature of life. Niels later developed this antinomy into one of his favorite examples of complementarity.[16] The other members of the group were a physicist, a philologist and a philosopher. Hence the conversations to which Niels listened as a boy underscored the ideals and difficulties of the search for unity in human knowledge. The philosopher of the group, Harald Høffding, was a particular influence as it was from him that Bohr received his only formal training in philosophy when he attended the University of Copenhagen.[17] Høffding was "an ardent student and brilliant expounder of Kierkegaard's teachings".[18] He criticized traditional speculative philosophy for its neglect of the role of the knowing subject and emphasized the fact that man is a participant as well as a spectator in life, a point frequently echoed in Bohr's writings.[19] Hence the importance of decision and discontinuity in science. Høffding also stressed the limitations of knowledge in the face of inexhaustible Being and the symbolic nature of all language.[20]

The direct influence of Kierkegaard was also very strong. We know that Niels read <u>Stages on Life's Way</u>[21] and recommended it highly to his brother.[22] Kierkegaard was one of the few writers whose influence Bohr readily acknowledged.[23] In addition to the formal epistemological points expounded by Høffding, Kierkegaard's influence on Bohr seems to have penetrated into his most basic attitudes like his avoidance of formal systems,[24] his relentless struggle with problems of analysis,[25] and his distrust of purely aesthetic considerations.[26] On the other hand, Bohr also had a keen sense of humor and he knew how to relieve excessive tension by telling a story or engaging in horseplay with his students.[27]

The only other influence which Bohr readily acknowledged was that of Poul Martin Møller's little book, Adventures of a Danish Student.[28] This was a half-serious account of an overly-introspective student who found himself paralyzed by the contradictions inherent in the process of formulating a thought. He discovered that each time he tried to observe the process he was confronted with a new process of observation which also needed to be observed. The result was an infinite series of egos, each observing the other, which is reminiscent of the problem of infinite regress that has plagued the quantum theory of measurement.[29] The moral of the story is that acting and reflecting on an action are two different things and one cannot do one while meeting the conditions of the other - a clear preview of the concept of complementarity.[30]

A strong case has been made for the possible influence of William James on Bohr's thought.[31] The evidence for this influence is as follows: (1) von Weizsäcker reports that the only philosophers Bohr often quoted with emphasis were Socrates and William James (quite a pair!). The similarity is seen especially in the dynamic mode of thought which resists systematization.[32] (2) Harald Høffding was a great admirer of William James. The two men met together in America in 1904, and Høffding devoted the concluding chapter of his Moderne Philosophischen (Danish 1904, German 1905)[33] to James's work in psychology.[34] James, in turn, wrote a preface for the English translation of Høffding's Problems of Philosophy in 1905.[35]

Undoubtedly, Høffding recommended James's writings to all his students (including Bohr). (3) Bohr concluded his original paper on complementarity (1928)[36] with reference to "a deep-going analogy to the general difficulty in the formation of human ideas, inherent in the distinction between subject and object."[37] This difficulty is also one of the principle themes of James's Principles of Psychology.[38] (4) Again at the conclusion of his second paper on complementarity (1929)[39] Bohr drew an analogy between "the apparent contrast between the continuous onward flow of associative thinking and the preservation of the unity of the personality."[40] According to Meyer-Abich and Jammer[41] this is a direct allusion to James's chapter on "The Stream of Thought".[42] (5) According to these same authors the very term, "complementarity", was taken from James's theory of hysterical anesthesia, according to which "in certain persons, at least, the total possible consciousness may be split into parts which coexist but mutually ignore each other, and share the objects of knowledge between them. More remarkable still, they are complementary."[43] (6) Finally, during a recorded interview on the day before his death, Bohr recalled that he had read James's chapter on "The Stream of Thought" and found it "really wonderful" and "most clear". When queried as to the time of this reading Bohr seemed vague at first but finally placed the event somewhere between 1905 and 1912.[44] These little bits of evidence have a certain cumulative force, but individually they appear circumstantial and inconclusive. Bohr did a good deal of thinking on his own about the problems of introspection, as we have seen, under the influence of Møller's essay. Therefore, most of the analogies cited above can be explained without recourse to the hypothesis of James's direct influence. Further, we are explicitly told by Bohr's closest associate, Leon Rosenfeld,[45] that Bohr was unfamiliar with the ideas of James when they were first brought to his attention in the early thirties although he then recognized a certain affinity with his own philosophy.[46] In view of the fact that Bohr never acknowledged the influence of James as clearly as he did that of Kierkegaard and Møller it would be best not to exaggerate its importance.

Finally, one should consider the direct influence of Max Planck and Albert Einstein more carefully than has been done previously. Usually they are represented as the champions of opposing schools in modern physics, but a closer look at their philosophies shows some striking parallells as we shall see in chapter 5. Planck and Einstein were the pioneers of the early quantum theory which Bohr developed, and Bohr repeatedly cited their work as the basis of his own.[47] Moreover, he frequently made appeals for Einstein's support for his ideas by drawing various parallels between the principle of complementarity and the theory of relativity.[48] These were often contrived, but they testify to the high respect Bohr had for his senior. We have already mentioned the influence of Einstein's many "thought experiments" on the development of Bohr's thinking,[49] but Einstein's influence appears to have been even deeper. Bohr's emphasis on physical principles rather than mathematical formalism may well have been inspired by the example of Einstein's early work.[50] Certainly Einstein's personal tribute to Bohr suggests that he recognized a strong affinity with his younger colleague:[51]

> What is so marvellously attractive about Bohr as a scientific thinker is his rare blend of boldness and caution; seldom has anyone possessed such an intuitive grasp of hidden things combined with a strong critical sense. With all his knowledge of the details, his eye is immovably fixed on the underlying principle. He is undoubtedly one of the greatest discoverers of our age in the scientific field.

1.3 The Criteria of Objective Knowledge - The Possibilities of Observation and Definition:

It seems almost impossible to arrange the different aspects of Bohr's philosophy in a systematic fashion.[52] There are only a half-dozen basic points, but they interrelate in a complex web rather than a linear progression, hence the exposition here is of necessity somewhat artificial. However, I have arranged the topics under three general headings which correspond roughly to epistemological, methodological, and ontological considerations. Although Bohr's philosophical writings extend over a thirty-five year period (1928-1963) and show definite signs of development, the basic ideas are unchanged in that they are clarified rather than modified, so I shall attempt an overall synthesis with only occasional references to the chronological development. I shall also try to compare some of Bohr's ideas with contemporary developments in philosophy, science, and theology in order to locate them in the wider scope of the history of modern thought.

Naturally, these comparisons should only be regarded as means to clarification and not as ends in themselves. The purpose of this chapter is simply to introduce and interpret Bohr's concept of complementarity within the context of his overall philosophy. Only in this way will it be possible to understand complementarity as he understood it and thus avoid the (all too common) error of importing alien concepts which have no place in Bohr's philosophy as a whole.

Bohr's basic epistemology is quite simple: all scientific knowledge must be <u>objective</u>, and the criterion for objectivity is <u>unambiguous communicability</u>.[53] Of course, this knowledge may be either true or false, but it is true or false independent of the individual judgement of the knowing subject.[54] In other words, there is no "subjective reference" in valid knowledge,[55] and, <u>in this sense</u>, no departure from our position as detached observers.[56]

A word about the criterion of unambiguous communicability which is the key to Bohr's philosophy: today we might compare it to the "intersubjectivity" or the "social coefficient" of knowledge and regard it as a novel idea in the philosophy of science,[57] but it has always played an important role in philosophy and especially in theology <u>when new realms of experience and knowledge are being explored</u>. In religious thought, for instance, there is a natural tendency to mysticism and ecstasy that has continually to be harnessed by the demands of community.[58] In this regard St. Paul recommended the gift of prophecy, which edifies others, over the gift of tongues, which is only of personal value (I Corinthians 14). Contemporary with the development of quantum mechanics there was a similar debate between Karl Barth and Paul Tillich. Barth's presupposition, like Bohr's, was that true knowledge must be capable of unambiguous formulation and proclamation.[59] Bohr's basic idea was neither new nor untimely.

In harmony with the requirement of unambiguous communicability, Bohr repeatedly stressed the importance of the <u>possibilities of unambiguous definition</u> in contrast to the possibilities of observation or measurement.[60] In his original paper on complementarity[61] he set aside Heisenberg's argument for the uncertainty principle, based on the impossibility of <u>measuring</u> the position and momentum of a particle simultaneously, in favor of an analysis of the conditions necessary for the <u>theoretical definition</u> of the concepts of position and momentum.[62] Using deBroglie's idea of representing a particle by a wave-group Bohr showed that the necessary conditions are mutually exclusive and thus demonstrated the uncertainty principle without reference to the process of measurement.[63] Years later, Bohr debated with Einstein over a similar point. The celebrated paper of Einstein, Podolsky and Rosen cited the prediction of the measured value of a physical quantity (position or momentum) as a sufficient condition for the physical reality of that quantity.[64] The authors then described a thought experiment which could not be explained by Heisenberg's measurement theory and concluded that quantum mechanics must necessarily be incomplete.[65] Bohr's response was to remind them that the problem was not just one of the prediction and measurement of physical quantities, but one of their unambiguous definition, and for this purpose it was always necessary to specify the entire experimental arrangement.[66] Thus the issue which separated Bohr from both Einstein and Heisenberg was the fundamental point of epistemology, the requirement of unambiguous communicability and definition.

1.4 The Role of Classical Concepts - Correspondence and Incommensurability:

The aim of all science, according to Bohr, is the exploration of new fields of experience in such a way that the requirement of unambiguous communicability is always satisfied, and this implies the use of a <u>common conceptual framework</u>.[67] Hence science embodies a dialectical tension:[68] it is only by experience that new laws of nature can be recognized while the content of experience can only be perceived and defined within a conceptual frame.[69] The existing framework will generally be too narrow to comprehend the new experience and have to be suitably adapted or widened,[70] but it cannot be entirely abandoned since there would then be no means of suitably defining a new framework and objectivity (in Bohr's sense) could no longer be maintained.[71]

In terms of philosophical categories, Bohr is here attempting a middle path between rationalism (the priority of the conceptual framework) and empiricism (the priority of sense experience).[72] He does this, however, not by means of compromise, but in a dialectical fashion, and the result is often confusing. Taken singly, some of Bohr's statements have led to charges of Kantianism,[73] on the one hand, and of positivism or crude empiricism,[74] on the other. But his intention is made clear by his repeated appeal to "the general lesson of philosophy regarding the necessity of a balance between analysis and synthesis," representing the ideals of rationalism and empiricism, respectively.[75]

For Bohr the common conceptual framework of science consists of ordinary language and logic as derived from practical, everyday life.[76] Ultimately we must fall back on these tools if we are to be understood by one another.[77] In physics, of course, one uses a specialized refinement of these tools in the concepts of classical physics.[78] When one develops a new field of physics, such as relativity or quantum theory, one finds that classical concepts, like wave, particle, and causality, are not completely adequate and must be suitably adapted or generalized, yet they may not be abandoned because they are necessary for the very recognition of the new kinds of phenomena which call them into question.[79] Hence Bohr's famous "correspondence principle" which guided the development of both quantum mechanics and quantum electro-dynamics:[80] "however far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms."[81] In this sense Bohr regarded quantum physics as the rational generalization of classical physics and complementarity as the rational generalization of the classical concept of causality.[82] And while he did not regard either quantum physics or complementarity to be final expressions of the laws of nature, he anticipated that further development would be based on them as they had been based on classical concepts.[83]

Some attempt should be made to relate the correspondence principle to its background in the history and philosophy of science. The view of the history of science implied by Bohr's approach is directly opposed to the models discussed today in the traditions of Karl Popper and Thomas Kuhn.[84] For Bohr, the three hundred years from Newton to Maxwell, the period of "classical physics", is not just another stage in the development of physics to be falsified or overthrown by scientific revolution as was the Aristotelian framework before it.[85] Classical physics is unique because it is perfectly adapted to the world of ordinary experience and cannot be improved as such. It is so consistent and beautiful that <u>it is bound to remain the language of physicists for all time</u>.[86] Relativity and quantum theory, then, do not supersede classical physics, as is often supposed, but are rather based upon it as rational generalizations suited to new, non-classical realms of experience.[87] And the verification, consistency and beauty of these new theories is such that future developments will be based upon them as further generalizations.[88] Hence, Bohr's model of the development of science is cumulative and constructionist[89] rather than cyclical or reductionist.

How does this compare with Einstein's view of scientific development? For Einstein, not only classical physics, but all of science is essentially "a refinement of everyday thinking".[90] One begins with the level of "primary concepts" which are directly and intuitively connected with everyday sense experience and proceeds to invent higher and higher levels of concepts with ever greater comprehensiveness, on the one hand, and logical unity (simplicity) and abstractness, on the other.[91] This "stratification of the scientific system" is comparable to Bohr's model if one takes the system of primary concepts to be ordinary language, the "secondary system" to be classical physics, the "tertiary system" to be quantum physics, and so on. But then several acute differences become apparent: (1) For Bohr, the "primary system" of everyday thinking is inseparable from sense experience since all experience is "theory-laden", whereas for Einstein the sense data are given and even the concepts of everyday thinking such as "the real world" are postulated or intuited from them.[92] (2) For Bohr, as for Einstein, the construction of the "secondary system" of classical physics is a matter of the refinement or specialization of everyday thinking, but the construction of the tertiary and higher systems is a process of "generalization" guided by the principle of correspondence whereas all these systems are "free mental creations" for Einstein.[93] (3) One would expect that Einstein's hierarchy would be more loosely-knit than Bohr's, but just the opposite is true. For Einstein, each level can be logically derived from the next higher level and can be reduced upwards, whereas for Bohr the various levels do not entail each other and are incommensurable in this sense.[94] Einstein's hierarchy is hypothetico-deductive and monolithic, whereas Bohr's hierarchy is correspondence-constructive and pluralistic. (4) Finally, Einstein's projected hierarchy is finite and convergent in the sense that he believed that higher levels would attain greater logical unity and simplicity as they increased in comprehensiveness until finally a minimal set of universal elementary laws would be reached from which all natural phenomena, including life, could be derived by pure deduction.[95] In contrast, Bohr's hierarchy is divergent and open-ended.[96] Quantum physics is a rational generalisation of classical physics, but it does not achieve a greater logical unity. To the contrary, the appearance of complementarity at this level achieves a greater degree of multiplicity,[97] and higher levels will undoubtedly move further in this direction.[98] This divergence could go on indefinitely for "we must continually count on the appearance of new facts, the inclusion of which within the compass of our earlier experience may require a revision of our fundamental concepts."[99] Furthermore, Bohr's hierarchy of correspondence is limited to physics (and chemistry) and does not include biology or the other sciences. In order to map out all of science a variety of hierarchies would be necessary, adding still further to the multiplicity and divergence.[100]

This comparison points up the great difference that existed between the visions of the two chief architects of modern physics. This difference was not simply a matter of taste, however; the two men actually saw the world differently. Einstein worked towards a unified field theory because he believed that nature was ultimately simple and economical.[101] Bohr worked towards a loose confederation of theories because he believed that nature was irreducibly complex and inexhaustible.[102]

Having examined the implications of the correspondence principle for the historical development of science, we turn now to its implications for scientific method. Feyerabend[103] has compared Bohr's principle in physics to <u>Hankel's principle of the permanence of calculating rules</u> in mathematics.[104] According to Hankel, the construction of a new mathematical system (e.g. the system of integers) as the generalization of an existing system (the system of natural numbers) should be done in such a way that as many rules of calculation are preserved as possible.[105] This principle guides the process of generalization without completely determining it.[106] Clearly, this is a very close parallel to Bohr's principle of correspondence, and one wonders whether there may have been a connection. While Bohr was not well-versed in number theory, himself, his brother, Harald, was a prominent mathematician and may well have brought this parallel to his attention. However, there is no direct evidence of this. On the other hand, the parallel breaks down in that in number theory the more general system always includes the less general one as a special case (e.g. natural numbers are positive integers), whereas in Bohr's model they are incommensurable.

A more suitable parallel could be drawn between the principle of correspondence and <u>the logic of models and metaphors</u>.[107] The scientist, the theologian, and the poet all use language analogically when exploring and describing new dimensions of reality.[108] A concept from everyday discourse is selected and applied to some new realm of discourse. This translation allows others to apprehend the new reality (hence the "disclosure model") and gradually to understand it. In the process the original concept is remolded and adapted to the structure of the new reality and its meaning is transformed.[109] Of course, it may turn out that the concept selected does not "fit" the new realm as well as some other in which case it may be discarded.

The way in which classical physics employs analogical language has been thoroughly studied: such concepts as force, mass, energy, space, wave and particle are known to be adapted from everyday discourse.[110] Bohr referred to this as a process of the refinement of everyday language.[111] Then his insistence on the use of classical concepts in non-classical fields is another instance of the analogical use of language,[112] though in this case Bohr referred to it as a "generalization" rather than a refinement or specialization.[113] Therefore, <u>the logic of correspondence may be regarded as a special case of the logic of analogy</u>.

This parallel is particularly helpful in view of the current debate over the dispensability or redundancy of analogies in science. The <u>formalist or axiomatic school</u> maintains that analogies may be heuristically helpful in the process of scientific discovery, but once a new theory has been found it should be completely formalized or axiomatized so that no "soft" heuristic or intuitive elements remain. The original theory is thereby completely reduced to the new one and the analogical connections can be discarded like the scaffolding of a new building.[114] In contrast, the <u>modellist or intuitionist school</u> maintains that no matter how much a new theory is axiomatized or how well formal asymptotic agreement with the old theory is achieved , the two are conceptually incommensurable and the analogical connections will always be essential for their proper interrelation.[115] On each point of this controversy Bohr would have to be classed as a modellist or intuitionist. Many of his critics disagree with him at this point.[116]

The dialectical interplay of correspondence and incommensurability has a further parallel in the work of the theologian.[117] From Hilary of Poitiers to Karl Barth, theologians have defended the use of analogies drawn from human experience in the apprehension of divine majesty while at the same time recognizing that God far transcends the limits of human concepts.[118] The problem is even more acute in theology than in science because God is believed to be infinitely transcendent and ineffable. On the other hand, God is also capable of actively revealing himself to man in analogical terms, whereas the hidden realities probed by science are generally passive and subject to man's initiative. So the parallel between science and theology is complicated by the reversal of roles (between subject and object) due to the fact that man is the middle term in the hierarchy, nature-man-God. Atoms cannot reveal themselves in the way God reveals himself. So even though all scientific thinking is based on analogy and correspondence we cannot say how or why these devices work and must ultimately appeal to some "pre-established harmony" or "miracle of comprehensibility" as Einstein did.[119] In theological terms, what is needed is a new understanding of the doctrine of common grace.[120]

1.5 The Subject-Object Relation and Complementarity:

In this section I hope to show how the requirements of unambiguous communicability and of classical language lead to the principle of complementarity. The argument is informal and follows Bohr's analysis of the subject-object relation. Polanyi's "from-at" relation will be cited for comparison.

From our discussion of the correspondence principle we know that a sharp distinction must be made between the (incommensurable) classical and quantum levels of reality, and hence between the measuring apparatus (the observing "subject") and the atomic object under observation.[121] These two levels are not related mechanically, as they were thought to be in classical physics, but <u>indivisibly as form and content</u>.[122] During an observation the measuring instrument constitutes the environment of the atomic object and so defines the very (boundary) conditions for its existence, its behaviour, and its properties.[123] Hence, a well-defined "observation" includes specification of the total environment of the object, and <u>in this sense</u> it is not permissible to discuss an object "in itself", outside of the conditions of observation.[124] The object certainly exists while it is not being observed (e.g. radiation in free space),[125] but its properties and behaviour are never independent of its macroscopic environment (free space). Hence to discuss the object meaningfully one must specify its environment, but this is precisely what we mean by "performing an observation". The issue here is actually one of <u>definition</u> (of the conditions under which the object exists) rather than observation in the (classical) mechanical sense.[126] The unknowability of the object as it is "in itself" is not due to the disturbance caused by the act of observation but to its dependence on the conditions of observation for its very existence.[127] The "thing-in-itself", with its inherent attributes, is not unknowable as if it were hidden; it is an idealization or abstraction that does not really exist.[128] In short, the existence and attributes of an object are relational, not absolute.[129]

Part of the confusion caused by Bohr's line of argument is due to his unusual use of the terms "observation" and "measurement" as the specification of experimental conditions, which he also refers to as "definition".[130] His treatment of the measuring apparatus or experimental conditions as "subject" is also unusual. The closest parallel is Polanyi's concept of "indwelling": man indwells the measuring apparatus when he uses it to define the conditions of observation and so makes it "subject".[131] Further confusion is caused by Bohr's dialectic of "sharp distinction" and "indivisibility". On one hand, Bohr will say that a sharp distinction is necessary between the observing subject, which exists on the classical level and must be described using the laws of classical physics, and the observed object, which exists on the quantum-mechanical level and is subject to quantum conditions like the uncertainty principle.[132] On the other hand, he will insist that no sharp distinction is possible since one is necessary for the definition of the other, and the two are inseparable or indivisible.[133] Hence his numerous references to the "indivisibility"[134] or "individuality"[135] or "wholeness"[136] or "completion"[137] of atomic phenomena which are, in this sense, "closed".[138] The paradox is troublesome but necessary as in any discussion of form and content: the two are inseparable yet utterly distinct.

Now the principle of complementarity can be approached from either side of this paradox, granted the requirement of unambiguous communicability. Since atomic object and experimental arrangement are inseparable one cannot abstract an object-in-itself and must always specify the experimental conditions in order to describe the object unambiguously[139] and satisfy the criterion for objective knowledge.[140] However, different types of experimental conditions are mutually exclusive even in classical physics.[141] There are kinematical variables like position and time, which require stationary measuring instruments for their definition, and dynamical variables like momentum and energy, which require freely-movable instruments.[142] Since these experimental conditions are mutually exclusive, so are the kinematical and dynamical properties of the atomic object which they define.[143] <u>Hence the atomic object exists in one of two modes which are "complementary" to each other</u>: a <u>particle-mode</u> in which the kinematical variables are defined ("space-time coordination") and a <u>wave-mode</u> in which the dynamical variables are defined ("the claim of causality").[144] In this sense, an atomic object is <u>either</u> a wave <u>or</u> a particle depending on its situation.

On the other hand, since object and experimental arrangement must be sharply distinguished, one must clearly specify the location of the boundary between them in order to ensure unambiguous description.[145] Bohr stressed that the location of the boundary is often a matter of choice on the part of the observer but it has a definite location in each experiment and cannot be shifted arbitrarily.[146] A change in the location of the boundary means a different experiment.[147] With regards to a measuring instrument, for instance, the boundary may be drawn on either side, and hence the instrument may belong to either of two ontological levels.[148] If the instrument is used as a tool to observe an atomic object, the boundary is drawn between the instrument (A) and the object (B) and the instrument is indwelt by the human subject (C).[149]

Subject	Object
C A	B

However, if the behaviour or structure of the instrument is analyzed, perhaps to determine the effect it has on the atomic object, it no longer functions as a tool and the boundary is drawn between the human subject and the instrument itself.[150]

Subject	Object
C	A B

Clearly, these two cases are mutually exclusive, hence the measuring instrument exists in one of two "complementary" modes, - either as a (classical) tool or as a (quantum-mechanical) object of investigation.[151]

The use of a measuring instrument or tool illustrates the most general form of complementarity, that between the analysis of A and the immediate application of A, or between A-analyzed and A-applied. Here "A" may represent a tool, a concept,[152] an emotion,[153] free-will,[154] life,[155] or the stability of an atom.[156] In each case, the ontological status of A (i.e. its mode of existence) depends on whether it is analyzed or applied.[157]

Take, for instance, the peculiar "supra-mechanical" stability of the atom, which was the puzzle that first led to the development of quantum physics and the principle of complementarity.[158] This stability requires the precise definition of energy and momentum by means of the classical conservation laws and is incompatible with any detailed observation of the atom's constituent particles in space and time. Any attempt to analyze this stability or the consergation laws, themselves, in terms of space-time pictures will result in a group of free particles rather than a stable atom.[159] Hence the atom exists in one of two modes, a stable wave-mode, in which momentum and energy states of the atom are well-defined and the "claim of causality" is satisfied, and an unstable particle-mode, in which the space-time location of the particles is observed.[160] In this sense, Bohr referred to space-time coordination and the claim of causality as "complementary but exclusive features of the description, symbolising the idealisation of observation and definition respectively."[161] In general, he regarded the complementarity between analysis and application as a confirmation of "the old truth that we are both onlookers and actors in the great drama of existence."[162]

The use of a measuring instrument also illustrates the general connection between the principles of correspondence and complementarity.[163] Correspondence is the relationship across the subject-object boundary, between the classical laws and concepts that apply to the measuring instrument and the non-classical features of the observed object.[164] In Polanyi's terminology, it is the "from-at" relation between the "proximal term" which man indwells and the "distal term" to which he attends.[165] Complementarity, on the other hand, is the relationship between the measuring instrument used as a classical tool for the investigation of a non-classical object and the same measuring instrument as a non-classical object of investigation in its own right. In Polanyi's scheme, it is the relationship between the instrument as "tacitly known" (applied) and as "specifiably known" (analyzed).[166] The logical connection is that the correspondence principle requires a sharp distinction between the ontological levels of the subject and the object, and proper attention to the placing of this boundary leads to the principle of complementarity. Alternatively, the correspondence principle implies the indivisibility of measuring apparatus and atomic object, and proper attention to the experimental arrangement leads again to the principle of complementarity.

The example of atomic stability brings out an important feature of Bohr's subject-object (correspondence) and analysis-application (complementarity) relations which is not present in the case of human artifacts (instruments and concepts): they do not depend on the presence or even

<u>on the existence of a human subject</u>. We know that atoms were stable long before man ever existed even though it is only as human subjects that we can speak of the laws of conservation and the demand of causality. Hence, Bohr's position is <u>essentially realist</u>; the structure of human knowledge (epistemology) has been adapted to the structure of reality (ontology) rather than the other way around. The principles of correspondence and complementarity are developed from an anthropocentric perspective, as they must be, but they are believed to reflect actual relations of being independent of and prior to man's knowledge of them. In this regard, Bohr's position must be clearly distinguished from that of Michael Polanyi.

Polanyi's "from-at" conception was cited above as a parallel to Bohr's subject-object relation. There are several important differences, however. For Polanyi, the shift from specifiable knowledge of A to tacit knowledge of A is really a change in the <u>appearance</u> of A due to the change in our <u>awareness</u> of A as we shift the focus of our <u>attention</u> from A to B.[167] For Bohr, on the other hand, the shift from specifiable to tacit knowledge of A reflects a change in the actual conditions under which A exists. The shift is ontological as well as epistemological for Bohr whereas it is basically epistemological for Polanyi.[168]

To illustrate this difference we may compare Bohr's and Polanyi's treatment of the use of a stick as a probe in a dark room. Both men agree that the subject may be aware of the feeling of the stick in his hand or else of the contact between the stick and the objects in the room, but not both at the same time. Polanyi explains this as a shift of awareness from one end of the stick to the other due to an interpretive effort on the part of the subject.[169] But Bohr sees it as a change in the actual handling of the stick itself: when it is held loosely it appears as an object in the hand, but when it is held firmly it functions as a probe and the sense of touch is automatically transferred to the other end.[170]

This basic difference leads to several others which we can only note briefly. Both Bohr and Polanyi apply their ideas to the relationship between ontological levels like those of physics and biology or those of body and mind. Bohr treats the relationship as one of complementarity between alternative modes of a single reality,[171] but Polanyi treats it as one between the proximal and distal terms of the knowing relation (Bohr's correspondence relation).[172] Hence, for Polanyi, it is not the higher level itself, but only our knowledge of it, that is unspecifiable in terms of its lower level particulars.[173] Both exist simultaneously, but only one can be specifiably known at a time. But for Bohr the two levels or modes are mutually exclusive in reality as well as in thought, hence it is not just our knowledge of the higher level, but the level itself, that is unspecifiable in terms of its lower level particulars.[174]

Finally, we may note that the use of "boundary conditions" by Bohr and Polanyi is entirely different.[175] In both cases the boundary conditions relate the proximal and distal terms of the knowing relation. However, for

Polanyi, the distal term is always the higher ontological level, hence it imposes the boundary conditions on the lower level proximal term which is not complete in itself.[176] For Bohr, on the other hand, the proximal term is always the experimental environment of the distal term, hence it defines the (boundary) conditions for the existence of the distal term.[177] There are no boundary conditions between two complementary modes or levels, and both higher and lower levels are complete in themselves.[178]

Having studied the philosophical background of the principle of complementarity, our purpose in the next chapter will be to examine in detail the structure of the complementarity relationship itself.

Footnotes: Chapter 1.

1. "Each word is carefully chosen and each sentence written and rewritten until it conveys the precise meaning intended." J.R.Nielson, "Memories of Niels Bohr", Physics Today 16(No.10), 1963, p.25.

2. "Bohr strove for clarity but the results were rather oracular." W.H.Austin, Waves, Particles, and Paradoxes, Houston, 1967, p.11. Some unfortunate student has subtitled the Edinburgh University Library copy of Bohr's original paper on complementarity "An Agglomeration of Verbosity"! ("The Quantum of Action and the Recent Development of Atomic Theory", Nature 121, 1928, p.580).

3. "Light and Life", Nature 131, 1933, pp.421-423, 457-459.

4. Atomic Physics and Human Knowledge, New York, 1958, pp. 3-12.

5. The best analyses of Bohr's writings to date are: P.K. Feyerabend, "Complementarity I", Proc.Arist.Soc. 32. 1958, pp.75-104, "Niels Bohr's Interpretation of the Quantum Theory", in H.Feigl and G.Maxwell, eds., Current Issues in the Philosophy of Science, New York, 1961, pp. 371-390, "Problems of Microphysics", in R.G.Colodny, ed., Frontiers of Science and Philosophy, Pittsburgh, 1962, pp.189-283, and "On A Recent Critique of Complementarity", Phil.Sci. 35, 1968, pp.309-331; A.Petersen, "The Philosophy of Niels Bohr", Bul.Atom.Sci., 19, 1963, pp.8-14, "Niels Bohr and the Philosophy of Science", in R. Klibansky, ed., Contemporary Philosophy, Vol.II: Philosophy of Science, Florence, 1968, pp.277-285., and Quantum Physics and the Philosophical Tradition, New York, 1968; K.M.Meyer-Abich, Korrespondenz,Individualität und Komplementarität, Wiesbaden, 1965; C.A.Hooker, "The Nature of Quantum Mechanical Reality: Einstein Versus Bohr", in R.G. Colodny, ed., Paradigms and Paradoxes, Pittsburgh, 1972, pp.67-302 (see especially fn.51 on p.262); and E.Scheibe, The Logical Analysis of Quantum Mechanics, Oxford, 1973, ch.1. Note that most of these essays have been published in the last ten years since Bohr died.

6. See the bibliography appended to this thesis. For a complete bibliography of all Bohr's writings see J.D. Cockcroft, "Niels David Bohr", Biographical Memoirs of Fellows of the Royal Society of London 9, 1963, pp.49-53; or L.Rosenfeld, "Niels Bohr (7 October 1885 - 18 November 1962)", Nuc.Phys. 41, 1963, pp.7-12.

7. Since these volumes will be cited repeatedly it will be convenient to abbreviate them as follows: ATDN = Atomic Theory and the Description of Nature, London, 1934; APHK = Atomic Physics and Human Knowledge, New York, 1958; Essays = Essays 1958-1962 on Atomic Physics and Human Knowledge, New York, 1963.

8. e.g. by C.F.von Weizsäcker, P.Jordan, L.Rosenfeld, and M.Born, respectively. These and other interpretations will be discussed in chapter 4.

9. A classic example is K.R.Popper, The Logic of Scientific Discovery, New York, 1968, p.454. Popper finds Bohr's formulations of the principle of complementarity "vague and difficult to discuss" so he takes recourse to P. Jordan's Anschauliche Quantentheorie! (Berlin, 1936).

10. "While Harald [Niels's brother] as a rule preferred to work alone, conversation was the way by which Niels Bohr developed his thoughts." S.Rozental et al., Niels Bohr, Amsterdam, 1967, p.25; "His turn of mind was essentially dialectical, rather than reflective; although he did of course spend long hours in solitary thought, often during sleepless nights, he needed the stimulus of some form of dialogue to start off his thinking." L.Rosenfeld, "Niels Bohr in the Thirties", in S. Rozental et al., op.cit., p.117. For a lively account of these conversations, see W.Heisenberg, Physics and Beyond, London, 1971.

11. "Discussion with Einstein on Epistemological Problems in Atomic Physics", in P.A.Schilpp, ed., Albert Einstein: Philosopher-Scientist, Evanston, 1949, pp.199-241 (reprinted in APHK, pp.32-66). The memory of the contest lingered on. A sketch of the famous "Einstein box" was found on Bohr's blackboard the day after he died; see the cover picture of Physics Today 16 (No.10), 1963. "This, I am convinced was Bohr's inexhaustible source of identity. Einstein appeared forever as his leading spiritual sparring partner - even after the latter's death he would argue with him as if Einstein were still alive." A.Pais, "Reminiscences of the Post-War Years", in S.Rozental et al., op.cit., p.219; cf. pp.128-129,225-226. On the earlier discussions between Bohr and Einstein (1923-1925) see M.J.Klein, "The First Phase of the Bohr-Einstein Dialogue", in R.McCormmach, ed., Historical Studies in the Physical Sciences, Vol.2, Philadelphia, 1970, pp.1-39.

12. For instance, in a 1913 address to the Physical Society in Copenhagen Bohr concluded that his semi-classical model of the hydrogen atom was intended to emphasize the conflict between classical and quantum theoretical concepts so "that it may also be possible in the course of time to discover a certain coherence in the new ideas"; see "On the Spectrum of Hydrogen", in The Theory of Spectra and Atomic Constitution, Cambridge, 1922, p.19. Gerald Holton has put the matter nicely: "...it seemed as if Bohr looked for and fastened with greatest energy on a contradiction, heating it to its utmost before he could crystallize the pure metal out of the dispute. Bohr's method of argument shared with the complementarity principle itself the ability to exploit the clash between antithetical positions." G.J.Holton, "The Roots of Complementarity", Daedalus 99, 1970, p.1044.

13. e.g. R.J.Hall, "Philosophical Basis of Bohr's Interpretation of Quantum Mechanics", Am.J.Phys. 33, 1965, pp. 624-627. Recently P.K.Feyerabend has done much to clear up these misunderstandings; see fn.5 above.

14. For a good general survey see G.J.Holton, loc.cit. and M.Jammer, The Conceptual Development of Quantum Mechanics, New York, 1966, pp.166-180. Bohr's independence of the traditional systems of philosophy and particularly of logical positivism has been stressed by L.Rosenfeld ("Niels Bohr in the Thirties", p.116), J.R.Nielson ("Memories of Niels Bohr", p.28), and W.Heisenberg (Physics and Beyond, pp.205-208).

15. S.Rozental et al., op.cit., p.13; L.Rosenfeld, Niels Bohr: An Essay, Amsterdam, 1945, pp.12-13.

16. O.Klein, "Glimpses of Niels Bohr as Scientist and Thinker", in S.Rozental et al., op.cit., p.76; cf. L.Rosenfeld, "Niels Bohr in the Thirties", p.132.

17. L.Rosenfeld, Niels Bohr: An Essay, p.12, "Niels Bohr's Contribution to Epistemology", Physics Today,16 (No.10), 1963, p.48. On Bohr's acknowledgement of this influence see H.Høffding, Correspondence entre Harald Høffding et Emile Meyerson, Copenhagen, 1939, p.149 (quoted in M. Jammer, op.cit., p.349, fn.77), and R.Moore, Niels Bohr: The Man and the Scientist, London, 1967, p.432.

18. M.Jammer, op.cit., p.173.

19. ATDN, p.119, APHK, pp.20,81. See below, ch.1.5.

20. M.Jammer. op.cit., pp.173-174.

21. Copenhagen, 1845. E.T., London, 1940.

22. "I even think it is one of the most delightful things I have ever read." Bohr's letter to his brother (1909), quoted in S.Rozental et al., op.cit., p.27.

23. "He made a powerful impression upon me when I wrote my dissertation in a parsonage in Funen, and I read his works night and day." Bohr quoted by J.R.Nielson, loc. cit., p.27.

24. "But I noticed that mathematical clarity was in itself no virtue for Bohr. He feared that the formal mathematical structure would obscure the physical core of the problem, and in any case, he was convinced that a complete physical explanation should absolutely precede the mathematical formulation." W.Heisenberg, "Quantum Theory and Its Interpretation", in S.Rozental et al., op.cit., p.98; cf. p.95 and M.Jammer, op.cit., p.347.

25. Bohr on Kierkegaard: "His honesty and willingness to think the problems through to their very limit is what is great...I admire his intensity and perseverance, his

analysis to the utmost limit, and the fact that through these qualities he turned misfortune and suffering into something good..." Quoted by J.R.Nielson, loc.cit.; cf. Rosenfeld on Bohr: "He vividly realized that our proud theories are but temporary resting places of the mind on the unending road to knowledge." "Niels Bohr's Contribution to Epistemology", p.49. Bohr has even been referred to as "the melancholy Dane"; see N. R.Hanson, The Concept of the Positron, Cambridge, 1963, p.96.

26. "In speculating about the prospects for some line of investigation, he would dismiss the usual considerations of simplicity, elegance and even consistency with the remark that such qualities can only be properly judged after the event." L.Rosenfeld, "Niels Bohr in the Thirties", p.117.

27. For some of the funniest see S.Rozental et al., op.cit., pp.112-113,306-307,328.

28. APHK, pp.13-14. The reference is to En Dansk Students Eventyr, Copenhagen, 1893.

29. See e.g. A.Daneri et al., "Quantum Theory of Measurement and Ergodicity Conditions", Nuc.Phys. 33, 1962, p.298 fn.; and M.A.Garstens, "Measurement Theory and Complex Systems", in T.Bastin, ed., Quantum Theory and Beyond, Cambridge, 1971, p.86. One wonders whether this infinite regress might never have arisen if von Neumann had studied Møller's little book as all of Bohr's students were required to do; see J.von Neumann, Mathematical Foundations of Quantum Mechanics, Princeton, 1955, pp.420-421.

30. Rosenfeld claims that Møller's essay introduced Bohr to Hegelian dialectics. There is no evidence for this claim, and one suspects Rosenfeld of contriving this connection between his favorite physicist and his favorite political philosopher. See Niels Bohr: An Essay, p.11, "Niels Bohr's Contribution to Epistemology", p. 48, and "Niels Bohr in the Thirties", p.121.

31. C.F.von Weizsäcker, "Komplementarität und Logik", Naturwis. 42, 1955, p.525; K.M.Meyer-Abich, op.cit., pp.133-140,154; and M.Jammer, op.cit., pp.176-179, 349-351; cf. H.P.Stapp, "The Copenhagen Interpretation", Am.J.Phys. 40, 1972, pp.1098-1116. For a thorough evaluation of the evidence see G.J.Holton, loc.cit., pp.1034-1038,1043.

32. C.F.von Weizsäcker, loc.cit., p.525.

33. E.T., Modern Philosophers, London, 1915.

34. K.M.Meyer-Abich, op.cit., p.133; M.Jammer, op.cit., p.176; and G.J.Holton, loc.cit., p.1040.

35. London, 1905.

36. "The Quantum Postulate and the Recent Development of Quantum Theory", Nature 121, 1928, pp.580-590 (reprinted in ATDN, pp.52-91).

37. "The Quantum Postulate, etc.", p.590 = ATDN, p.91.

38. M.Jammer, op.cit., p.349. The Principles of Psychology was published in London in 1890.

39. "Wirkungsquantum und Naturbeschreibung", Naturwis. 17, 1929, pp.483-486 (E.T., "The Quantum of Action and the Description of Nature", ATDN, pp.92-101).

40. ATDN, pp.99-100.

41. K.M.Meyer-Abich, op.cit., pp.133-134; M.Jammer, op.cit., pp.349-350; cf. pp.178-179.

42. The Principles of Psychology, Vol.1, ch.9, pp.224-290, esp. pp.243-244.

43. ibid, pp.206-207; quoted by M.Jammer, op.cit., p.350 (cf. K.M.Meyer-Abich, op.cit., p.154). If Jammer is right about this, it is strange that Bohr never developed the analogy himself (it is only briefly mentioned in APHK, p.77). In fact, it was later developed by P. Jordan (Verdrängung und Komplementarität, Hamburg-Bergedorf, 1947, pp.45-46). Jordan, however, cites the theories of Freud rather than those of James as precedent. See below, ch.4.6.

44. The interview was conducted by Aage Petersen and Thomas S. Kuhn on Nov.17, 1962 for the Archive for the History of Quantum Physics project sponsored by the American Physical Society and the American Philosophical Society. The relevant portion is quoted in G.J.Holton, loc.cit., pp.1034-1035.

45. Niels Bohr: An Essay, p.13, and "Niels Bohr's Contribution to Epistemology", p.52. Also see Rosenfeld's correspondence with H.P.Stapp, (loc.cit., p.115) and with G.J.Holton (loc.cit., p.1035).

46. Heisenberg seems to support Rosenfeld on this point; see Physics and Beyond, p.135 and G.J.Holton, loc.cit., p.1052, Note 30.

47. e.g. "Mathematics and Natural Philosophy", Scientific Monthly 82, 1956, p.86.

48. "Indeed, we find ourselves here on the very path taken by Einstein of adapting our modes of perception borrowed from the sensations to the gradually deepening knowledge of the laws of Nature." "The Quantum Postulate, etc.", p.590 = ATDN, p.90; cf. APHK, p.7, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", Phys.Rev. 48, 1935, pp.701-702, and Essays, pp.6-7.

49. See fn.11 above. This influence has been recognized by P.K.Feyerabend: "Complementarity I", pp.97-98, "Problems of Microphysics", p.219, and "On a Recent Critique of Complementarity I", pp.312-313, fn.9.

50. "Bohr's habit always to distinguish between formalisms and their physical content and his attempts to make this content as clear as possible in a qualitative way have their exact parallel in Einstein's insistence that 'the main thing is the content, not the mathematics'." P.K.Feyerabend, "On a Recent Critique of Complementarity II", p.88, fn.70; cf. p.83, fn.55, p.87, fn.67, and "I", pp.313-314, fn.12.

51. "Niels Bohr"; written sometime before 1923; reprinted in The World As I See It, London, 1935, pp.162-163; cf. Bohr's tribute to Einstein: "Albert Einstein: 1879-1955", Sci.Am. 192 (No.6), 1955, p.31.

52. Bohr regarded his clearest statement of his position to be "Quantum Physics and Philosophy - Causality and Complementarity", in R.Klibansky, ed., Philosophy in the Mid-Century; A Survey, Vol.1: Logic and Philosophy of Science, Florence, 1958, pp.308-314 (reprinted in Essays, pp.1-7).

53. "Every scientist, however, is constantly confronted with the problem of objective description of experience, by which we mean unambiguous communication." APHK, p.67; cf. Essays, pp.3,10,14. The earliest explicit statement of this criterion is found in "Physical Science and the Study of Religions", in Studia Orientalia Ioanni Pedersen, Copenhagen, 1953, p.386, hence it may have crystallized in response to critics' charges of subjectivity (cf. APHK, p.2). Previously Bohr had denied the existence of objective reality in the sense of independent reality (ATDN, pp.21,93,115, APHK, p.7; see below, ch.1.5). But the stress on unambiguity was present from the start (ATDN, p.16), and the criterion of communicability was always implicit in the requirement of the reproducibility of experimental conditions as Bohr himself points out (APHK, pp.25-26; cf. "Newton's Principles and Modern Atomic Mechanics", in Newton Tercentenary Celebrations, Cambridge, 1948, p. 59). In fact, the later emphasis on communication may well have been precipitated by Bohr's growing involvement in problems of international cooperation after the second world war; see "Energy from the Atom: An Opportunity and a Challenge", The Times, Aug.11, 1945, p.5, "A Challenge to Civilization", Science 102, 1945, pp.363-364, and "Atomic Physics and International Cooperation", Proceedings of the American Philosophical Society 91, 1947, pp.137-138.

54. "In this respect our task must be to account for such experience in a manner independent of individual subjective judgement and therefore objective in the

sense that it can be unambiguously communicated in the common human language." Essays, p.10; cf. pp.24,60. Again the earliest explicit statement is quite late (1960).

55. "The description of atomic phenomena has in these respects a perfectly objective character, in the sense that no explicit reference is made to any individual observer..." Essays, p.3; cf. p.7, and APHK, pp.68, 91. The earliest of these statements is 1955.

56. "The notion of complementarity does in no way involve a departure from our position as detached observers of nature, but must be regarded as the logical expression of our situation as regards objective description in this field of experience." APHK, p.74; cf. p.76 (1955).

57. See e.g. P.L.Berger and T.Luckmann, The Social Construction of Reality, London, 1971, pp.33ff.

58. See M.Halbwachs, Les Cadres Sociaux de la Mémoire, Paris, 1952, pp.201-221; A.J.Heschel, The Prophets, New York, 1962, pp.360ff.

59. "The knowledge of God is true knowledge and not vague surmise and sentiment. As knowledge it has to be expressed in words. It cannot spare itself the trouble of formulation. The objectivity of God in His revelation has to be taken seriously, so that in regard to God we cannot be content merely with a devout silence and a rapturous whisper." Church Dogmatics II.1, Edinburgh, 1957, ch.29, p.336; cf. I.1, Edinburgh, 1936, ch.3, pp.69-70.

60. "The Quantum Postulate, etc.", pp.580,582-583,585,586, "Causality and Complementarity", Phil.Sci. 4, 1937, pp.295,296, and Essays, p.5.

61. "The Quantum Postulate and the Recent Development of Atomic Theory", Nature 121, 1928, pp.580-590 (reprinted in ATDN, pp.52-91). This paper was first read before a congress of physicists at Como, Italy on September 16, 1927.

62. "The essence of this consideration /of Heisenberg's/ is the inevitability of the quantum postulate in the estimation of the possibilities of measurement. A closer investigation of the possibilities of definition would still seem necessary in order to bring out the general complementary character of the description." "The Quantum Postulate, etc.", pp.582-583 = ATDN, p.63. Bohr went on to point out that Heisenberg's argument alone does not rule out the possibility that a particle always has a precise position and momentum in spite of the fact that these cannot be measured simultaneously (cf. "Causality and Complementarity", pp.292-293,

Essays, p.5, and A.Petersen, op.cit., pp.110-111,145-146). Many of Bohr's critics have entirely missed this point and accused Bohr of basing his case on the limits of observability; e.g. M.Bunge, "Strife About Complementarity", B.J.P.S. 6, 1955, pp.2-3, 144-145; A. Landé, "From Duality to Unity in Quantum Mechanics", in H. Feigl and G.Maxwell, eds., op.cit., p.355; and H. Mehlberg, "Space, Time, Relativity", in Y.Bar-Hillel, ed., Logic, Methodology and Philosophy of Science, Amsterdam, 1965, p.377. Grünbaum, however, has recognized that for Bohr the limits of measurement must be theoretically significant; A. Grünbaum, "Complementarity in Quantum Physics and Its Philosophical Generalization", J.Phil. 54, 1957, pp.713-727. See also A. Petersen, "On the Philosophical Significance of the Correspondence Argument", in R.S.Cohen and M.W. Wartofsky, eds., Boston Studies in the Philosophy of Science, Vol.5, Dordrecht, 1969, p.247.

63. "The Quantum Postulate, etc.", pp.581-583 = ATDN, pp. 57-63.

64. "If without in any way disturbing a system we can predict with certainty the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." A.Einstein, B.Podolsky and N.Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?", Phys.Rev. 47, 1935, p.777.

65. ibid, p.780.

66. "Indeed we have in each experimental arrangement suited for the study of proper quantum phenomena not merely to do with an ignorance of the value of certain physical quantities, but with the impossibility of defining these quantities in an unambiguous way." N.Bohr, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" Phys.Rev. 48, 1935, p.699; cf. pp.700,701, and Essays, p.5. On the relevance of the experimental arrangement see below, ch.1.5.

67. "For the requirement of communicability of the circumstances and results of experiments implies that we can speak of well defined experiences only within the framework of ordinary concepts." "Causality and Complementarity", p.293; cf. APHK, p.68, and Essays, p.6.

68. Bohr avoided using the term "dialectic". The only instances are found in his contribution to the journal Dialectica: "On the Notions of Causality and Complementarity", Dialectica 2, 1948, pp.317,318 = Science 111, 1950, pp.53,54.

69. "...any account of experience even in atomic physics must ultimately rest on the use of the concepts

indispensable for a conscious recording of sense impressions." APHK, p.21. cf. "The Quantum Postulate, etc.", p.580 = ATDN, p.54. Hence "the subjective character of all experience" (ATDN, p.1), a phrase which Bohr later avoided; cf. fns.45-47 above.

70. "The task of science is both to extend the range of our experience and to reduce it to order....Only by experience do we come to recognize those laws which grant us a comprehensive view of the diversity of phenomena. As our knowledge becomes wider, we must always be prepared, therefore, to expect alterations in the points of view best suited for the ordering of our experience. In this connection we must remember, above all, that, as a matter of course, all new experience makes its appearance within the frame of our customary points of view and forms of perception." ATDN, p.1; cf. "Physical Science and the Study of Religions", p.390, and APHK, pp.65,67,82,88. The importance of the tension between form and content in Bohr's thought has been stressed by L.Rosenfeld, Niels Bohr: An Essay, pp.4-6, A.Petersen, "The Philosophy of Niels Bohr", p.10, and D.Bohm, "On Bohr's View Concerning the Quantum Theory", in T.Bastin, ed., op.cit., p.33.

71. "We must not forget that, in spite of their limitation, we can by no means dispense with those forms of perception which colour our whole language and in terms of which all experience must ultimately be expressed." ATDN, p.5.

72. "The epistemological primacy of the conceptual framework is not to be interpreted in an Idealist sense. Nor does it signify that ontology is relative to a linguistic scheme." A.Petersen, op.cit., p.187.

73. e.g. C.F.von Weizsäcker, "Komplementarität und Logik", p.525, and "The Copenhagen Interpretation", in T.Bastin, ed., op.cit., p.28. von Weizsäcker was sympathetic to Bohr but interpreted him from a Kantian perspective; see below, ch.4.4.

74. e.g. P.K.Feyerabend, "An Attempt at a Realistic Interpretation of Experience", Proc.Arist.Soc., N.S. 58, 1957-1958, p.143. Feyerabend later modified the charge to "positivism of a higher order" ("Complementarity I", pp.80-81); see below, ch.5.8.

75. "Causality and Complementarity", p.294. This oblique reference to analytic and synthetic propositions is the closest Bohr ever came to using philosophical jargon; cf. APHK, p.65, and "Analysis and Synthesis in Science", in O.Neurath et al., eds., Foundations of the Unity of Science, Vol.1, Chicago, 1955, p.28. In the same manner Bohr frequently referred to a balance between comprehensiveness and logical consistency: e.g. APHK, p.80.

76. "Our basic tool is, of course, plain language which serves the needs of practical life and social intercourse..." APHK, p.67; cf. p.88

77. "Just the requirement that it be possible to communicate experimental findings in an unambiguous manner implies that the experimental arrangement and the results of the observation must be expressed in the common language adapted to our orientation in the environment." Essays, p.78; cf. pp.3,24, and APHK, pp.25-26,39,72,89.

78. e.g. Essays, pp.3,24.

79. "The quantum theory is characterized by the acknowledgement of a fundamental limitation in the classical physical ideas when applied to atomic phenomena. The situation thus created is of a peculiar nature, since our interpretation of the experimental material rests essentially upon the classical concepts." These are the opening words of Bohr's original paper on complementarity; "The Quantum Postulate, etc.", p.580 = ATDN, p.53.

80. ATDN, p.8. The correspondence principle was first explicitly stated in 1918: "On the Quantum Theory of Line-Spectra", Kongelige Danske Videnskabernes Selskabs Skrifter Naturvidenskabelig og mathematisk afdeling, Series 8, 4 (No.1), 1918, p.8; cf. The Theory of Spectra and Atomic Constitution, pp.23-24. On the historical development of the correspondence principle see K.M. Meyer-Abich, op.cit., pp.72-93, and M.Jammer, op.cit., pp.109-118. For a recent interpretation in terms of group theory see A.Komar, "The Quantitative Epistemological Content of Bohr's Correspondence Principle", Synthése 21, 1970, pp.83-92. N.B. Bohr's correspondence principle is not to be confused with Nagel's "correspondence rules" between theory and experiment (The Structure of Science, New York, 1961, pp.90-105).

81. APHK, p.39; cf. p.72, and Essays, p.11.

82. "The Quantum Postulate, etc.", pp.581,584,589 = ATDN pp.56,70,87, and APHK, pp.27,41,73,90. Here "generalization" is to be distinguished from "refinement", the latter being a kind of specialization. Classical physics is a refinement of everyday thinking; the two are adapted to the same level of experience, but only the former is formalized. Quantum physics is a generalization of classical physics; both are formalized, but they apply to different ontological levels.

83. "On closer consideration, the present formulation of quantum mechanics in spite of its great fruitfulness would yet seem to be no more than a first step in the necessary generalization of the classical mode of description...For a correlation of still deeper lying

laws of nature...we must be prepared for a more comprehensive generalization of the complementary mode of description which will demand a still more radical renunciation of the usual claims of so-called visualization." "Causality and Complementarity", p.294. In spite of this, Bohr is frequently criticized for holding that complementarity is the ultimate development in physics; e.g. M.Bunge, "Strife About Complementarity", pp.144-145 in spite of L.Rosenfeld's earlier "Strife About Complementarity", Science Progress 41, 1953, pp.408-409.

84. See K.Popper, The Logic of Scientific Discovery, and Conjectures and Refutations, London, 1963; T.S.Kuhn, The Structure of Scientific Revolutions, Chicago, 1970; I.Lakatos and A.Musgrave, eds., Criticism and the Growth of Knowledge, Cambridge, 1970.

85. Contrast the cyclical view of Feyerabend in "Problems of Microphysics", pp.228,231, and "Bohr's Interpretation of Quantum Theory", pp.387-390.

86. "Maxwell and Modern Theoretical Physics", Nature 128, 1931, p.692. The issue here again is one of definition and communication, not the length of time classical physics held the field (Aristotelian physics held it longer) or a "vicious circle between paradigm and observations" or a "principle of pragmatic meaning" as Feyerabend suggested in one of his earlier articles; "An Attempt at a Realistic Interpretation of Experience", pp.152-153; see below, ch.5.8.

87. e.g. "The Quantum Postulate, etc.", p.590 = ATDN, pp. 90-91, and "Can Quantum-Mechanical Description, etc.", p.701, and APHK, p.73. Hence, classical physics is not contained by quantum physics (or by relativity) as a "limiting case" even though an asymptotic numerical agreement ensures consistency. In current philosophical terms the two are "incommensurable"; see "The Quantum Postulate, etc.", p.589 = ATDN, pp.85,87; M.Jammer, op. cit., pp.117,219; P.K.Feyerabend, "On a Recent Critique of Complementarity I", pp.315-320; and D.Bohm, Quantum Theory, New York, 1951, pp.624-628.

88. e.g. "Causality and Complementarity", p.294.

89. By "constructionist" I mean simply that Bohr's model is built from the ground (classical physics) upward but is not reducible upwards. There is no relation to Bridgman's "mental constructs" (The Logic of Modern Physics, New York, 1927, pp.53,59).

90. Ideas and Opinions, London, 1954, p.290; cf. p.324.

91. ibid, pp.292-294.

92. ibid, pp.290-292.

93. *ibid*, p.291.

94. *ibid*, p.294. Hence for Einstein quantum theory is a touchstone for any future theory in the sense that it must be deducible as a limiting case, but it cannot serve as the starting point in the search for new theories, whereas just the reverse is true for Bohr; *ibid*, p.319, and "Quantum Mechanics and Reality", in *The Born-Einstein Letters*, London, 1971, p.169 (E.T. of "Quanten-Mechanik und Wirklichkeit", *Dialectica* 2, 1948, pp.320-324).

95. *ibid*, pp.226,274,294,324,357. Belief in the attainability of this ideal animated all of Einstein's research; cf. *The Born-Einstein Letters*, p.149.

96. *contra* Feyerabend who fears that the method of natural generalization will lead to stagnation; "Complementarity I", pp.103-104.

97. Whereas general relativity relates space-time geometry directly to the energy-momentum tensor, quantum theory makes space-time description complementary to the definition of energy and momentum; cf. A.Einstein, *The Meaning of Relativity*, London, 1956, pp.80-81.

98. "Causality and Complementarity", p.294.

99. *ATDN*, p.97.

100. Such a map will be constructed in chapter 3; cf. G. Ludwig, "Gelöste und ungelöste Probleme des Messprozesses in der Quantenmechanik", in F.Bopp, ed., *Werner Heisenberg und die Physik unserer Zeit*, Braunschweig, 1961, p.159.

101. *Ideas and Opinions*, pp.274,357.

102. *APHK*, pp.80,82.

103. "Problems of Microphysics", p.264. Feyerabend credits Aage Petersen, one of Bohr's students, with suggesting this comparison to him.

104. H.Hankel, *Vorlesungen über die complexen Zahlen*, Leipzig, 1867.

105. F.Waismann states Hankel's principle as follows: "If we wish to extend a concept in mathematics beyond its original definition, then among all the possible directions of this extension the one is to be chosen that will leave the calculating rules intact as far as possible." *Introduction to Mathematical Thinking*, London, 1951, p.27.

106. *ibid*, pp.27,47-48.

107. cf. E.H.Hutten, "The Role of Models in Physics". B.J.P.S. 4, 1954, p.301, The Language of Modern Physics, London, 1956, pp.162-165, and "Scientific Models", in R.Klibansky, ed., Contemporary Philosophy; A Survey, Vol.II: Philosophy of Science, p.124.

108. e.g. M.Black Models and Metaphors, Ithaca, 1962, chs. 3,13; and I.T.Ramsey, Models and Mystery, London, 1964; cf. P.Henle "Mysticism and Semantics", Phil.Phen.Res. 9, 1949, pp.416-422.

109. Correspondence is the relation between the original and adapted forms of the concept, while analogy is the relation between this dipolar concept (the analogue) and its counterpart, the reality to which it is adapted. Here I must disagree with Pannenberg's view of analogy as the relation between the everyday meaning of a word and its specialized (theological) use (Basic Questions in Theology, Volume One, London, 1970, pp.217f). This is really correspondence (and incommensurability). The problem of equivocity is resolved when the dipolar nature of the analogue is kept in mind.

110. Sometimes via metaphysics; see E.A.Burtt, The Metaphysical Foundations of Modern Science, New York, 1952; M.Hesse, Forces and Fields, London, 1961; and M.Jammer, articles on "Energy", "Force", and "Mass" in The New Catholic Encyclopedia, New York, 1966, Concepts of Force, Cambridge, Mass., 1957, Concepts of Mass, Cambridge, Mass., 1961, and Concepts of Space, Cambridge, Mass., 1969.

111. See above, esp. fn.78.

112. The correspondence principle requires description "by means of different analogies taken from our usual ideas." APHK, p.27. Note: since these are taken from classical physics they are really second or third order analogies.

113. See above, fn.82.

114. e.g. P.Duhem, The Aim and Structure of Physical Theory, Princeton, 1954, Part 1, ch.4; N.R.Campbell, Physics, The Elements, Cambridge, 1920, ch.6; E.Nagel, The Structure of Science, pp.90-116; R.B.Braithwaite, Scientific Explanation, Cambridge, 1953, ch.4, and "Models in the Empirical Sciences", in E.Nagel et al., eds., Logic, Methodology and Philosophy of Science, Stanford, 1962, pp.224-231; C.G.Hempel, Aspects of Scientific Explanation, New York, 1965, pp.433-447; M.Bunge, Intuition and Science, Englewood Cliffs, 1962, p.107, and "Analogy in Quantum Theory: From Insight to Nonsense", B.J.P.S. 18, 1967, esp. pp.280-282 from which the following quote is taken: "If we want to build or learn new theories then we are likely to use analogy as a bridge between the known and the unknown.

But as soon as the new theory is on hand it should be subjected to a critical examination with a view to dismounting its heuristic scaffolding and reconstructing the system in a literal way - this being one of the uses of axiomatisation...To suggest that scientific explanation is metaphorical is to mistake scientific theories for biblical parables or to subscribe to instrumentalism."

115. e.g. S.Toulmin, The Philosophy of Science, London, 1953, ch.2.4; M.Hesse, "Models in Physics", B.J.P.S. 4, 1953, pp.198-214, Forces and Fields, pp.13-28, and Models and Analogies in Science, London, 1966; H.Freudenthal, ed., The Concept and the Role of the Model in Mathematics and Natural and Social Sciences, Dordrecht, 1961; M. Black, op.cit., ch.13; P.Achinstein, "Models, Analogies, and Theories", Phil.Sci. 31, 1964, pp.328-350, "Theoretical Models", B.J.P.S. 16, 1965, pp.102-120, and Concepts of Science, Baltimore, 1968, chs.7-8; M.Spector, "Models and Theories", B.J.P.S. 16, 1965, pp.121-142; J.W.Swanson, "On Models", B.J.P.S. 17, 1966, pp.297-311; E.McMullin, "What Do Physical Models Tell Us?", in B.van Rootselaar and J.F.Stall, eds., Logic, Methodology and Philosophy of Science, Amsterdam, 1968, pp.385-396; H.Byerly, "Model-Structures and Model-Objects", B.J.P.S. 20, 1969, pp.135-144; and J.C. Carloye, "An Interpretation of Scientific Models Involving Analogies", Phil.Sci. 38, 1971, pp.562-569. There is considerable difference in detail among these authors, but they share the fundamental conviction that models and analogies are essential and irreducible in scientific method. On the irreducible role of metaphor in both science and literature see e.g. M.Black, "Metaphor", Proc.Arist.Soc. 55, 1954, pp.273-294 (reprinted in op.cit., ch.3); M.C.Beardsley, Aesthetics, New York, 1958, pp.134-144, 432-437; P.Henle, "Metaphor", in P.Henle, ed., Language, Thought, and Culture, Ann Arbor, 1958, pp.173-195; D.Bergren, "The Use and Abuse of Metaphor", Review of Metaphysics 16, 1962-63, pp.237-258, 450-472; D.Schon, The Displacement of Concepts, London, 1963; W.P.Alston, Philosophy of Language, Englewood Cliffs, 1964, pp.96-106; M.Hesse, "The Explanatory Function of Metaphor", in Y.Bar-Hillel, ed., op.cit., pp.249-259 (reprinted in Models and Analogies in Science, pp.157-177; and E.R.MacCormac, "Meaning Variance and Metaphor", B.J.P.S. 22, 1971, pp.145-159.

116. e.g. K.Popper and M.Bunge; see below, ch.5.7.

117. On the use of models in theology see D.Emmet, The Nature of Metaphysical Thinking, London, 1945, chs.4-5; I.T. Ramsey, Religious Language, New York, 1963, ch.2, Models and Mystery, and Christian Discourse, London, 1965; F.Ferré, Language, Logic and God, New York, 1969, and "Mapping the Logic of Models in Science and Theology", The Christian Scholar 46, 1963, pp.9-39 (reprinted

in D.High, ed., New Essays on Religious Language, New York, 1969, pp.54-96); A.A.Glenn, "Criteria for Theological Models", Scot.J.Th. 25, 1972, pp.296-308; and R.P.Scharlemann, "Theological Models and Their Construction", J.Rel. 53, 1973, pp.65-82.

118. Hilary, On the Trinity, Oxford, 1894, I.19, IV.2, VI.9, VII.30, VIII.16; K.Barth, Church Dogmatics, II.1, ch. 27, pp.227-228,236, and ch.29, pp.341-342.

119. Ideas and Opinions, pp.226,292.

120. cf. T.F.Torrance, Theology in Reconstruction, London, 1965, pp.30,56,93-94,257.

121. "The main point here is the distinction between the objects under investigation and the measuring instruments which serve to define, in classical terms, the conditions under which the phenomena appear." APHK, p.50; cf. p.91, and Essays, pp.3-4,78.

122. "Can Quantum-Mechanical Description, etc.", p.700, APHK, pp.63-64,72-74,90,98-99. The importance of Bohr's denial of a mechanical connection has been recognized by J.Bub ("The Daneri-Loinger-Prosperi Quantum Theory of Measurement", Nuo.Cim., Series 10, 57B, 1968, p.507, "Hidden Variables and the Copenhagen Interpretation - A Reconciliation", B.J.P.S. 19, 1968, p.190) and D.Bohm ("On Bohr's Views Concerning the Quantum Theory", pp.33,37.38); see also D.Faggiani, "Fisica Quantistica e Tradizione Filosofica", Scientia 106, 1971, pp.993-1003. On the relation between form and content see fn.70 above.

123. "In quantum physics, we can in fact no longer uphold customary ideas of properties and behaviour of the objects under investigation as separate from the interaction between such objects and the measuring instruments, indispensable for the definition of the circumstances under which the phenomena occur." "Physical Science and the Study of Religions", p.387; cf. APHK, pp.39-40,47,50,52, and Essays, p.78.

124. "On the lines of objective description, it is indeed more appropriate to use the word phenomenon to refer only to observations obtained under circumstances whose description includes an account of the whole experimental arrangement." APHK, p.73; cf. p.64.

125. "The Quantum Postulate, etc.", p.580 = ATDN, p.55. If asked whether there is sound when a tree falls in the woods with nobody around to hear, Bohr would answer "yes" because the conditions of the phenomenon have been specified and an "observation" (here a "thought experiment") has been performed in this sense; cf. J. Wahl, "Physique Atomique et Conaissance Humaine", Rev. Mét.Mor. 67, 1962, p.253.

126. The word "observation" is used here in two opposite senses; a classical sense in which Bohr contrasts it with "definition" (see ch.1.3 above) and a quantum-mechanical sense in which it means the specification of circumstances or environment (the experimental arrangement) and hence involves the idea of definition. Incidentally, there is no connection here with Bridgman's use of "operational definitions" (op.cit., p.5) since Bohr's reasoning is fundamentally ontological rather than epistemological.

127. "All confusion arises, in fact, from the use of such utterances as 'disturbance of phenomena by their observation', a phrase equally irreconcilable with any unambiguous meaning of the very words 'observation' and 'phenomenon'." "Newton's Principles, etc.", pp.59-60; cf. APHK, pp.64,73, and Essays, p.3. For Bohr the limits of knowledge are imposed by nature, not by man; see ATDN, p.115. As Feyerabend points out, Bohr's ban on "disturbance"-talk is late (1947) and reflects the objections of Einstein, Podolsky and Rosen (loc.cit.); see "Complementarity I", pp.97-98, and "Problems of Microphysics", p.219. However, it was always implicit in Bohr's distinction between the possibilities of observation and the possibilities of definition; see ch. 1.3 above.

128. "The whole situation in atomic physics deprives of all meaning such inherent attributes as the idealizations of classical physics would ascribe to the object." "Causality and Complementarity", p.293; cf. p.291, and "The Quantum Postulate, etc.", pp.581,584,586,587. The reference to "hidden secrets" in APHK, p.9 = "Light and Life", p.458 was an unfortunate figure of speech which Bohr never repeated.

129. "...no result of an experiment concerning a phenomenon which, in principle, lies outside the range of classical physics can be interpreted as giving information about independent properties of the objects, but is inherently connected with a definite situation in the description of which the measuring instruments interacting with the objects also enter essentially." APHK, p.26. It is in this context that one should properly understand Bohr's most criticized statement: "We meet here in a new light the old truth that in our description of nature the purpose is not to disclose the real essence of the phenomena but only to track down, so far as it is possible, relations between the manifold aspects of our experience." ATDN, p.18; cf. P.K.Feyerabend, "Problems of Microphysics", pp.217-220. Bohr rejected both idealism and realism as philosophical positions since he accepted neither an ultimate subject nor an independent object; see APHK, pp.51,79.

130. See fn.126 above. Among critics who have missed this point are E.E.Witmer, "Interpretation of Quantum Mechanics and the Future of Physics", Am.J.Phys. 35, 1967,

pp.45-46; and B.d'Espagnat, "Things, Structures and Phenomena in Quantum Physics", in B.van Rootselaar and J.F.Stall, eds., op.cit., p.381.

131. M.Polanyi: "Our subsidiary awareness of tools and probes can be regarded now as the act of making them form a part of our own body...We pour ourselves out into them and assimilate them as parts of our own existence. We accept them existentially by dwelling in them." Personal Knowledge, London, 1958, p.59; cf. The Tacit Dimension, New York, 1967, p.16. Bohr also spoke of tools as extensions of man, drawing an analogy between the process of repair and the process of healing; see W.Heisenberg, Physics and Beyond, p.109.

132. "The essentially new feature in the analysis of quantum phenomena is, however, the introduction of a fundamental distinction between the measuring apparatus and the objects under investigation. This is a direct consequence of the necessity of accounting for the functions of the measuring instruments in purely classical terms, excluding in principle any regard to the quantum of action." Essays, pp.3-4; cf. p.78, and APHK, pp.50,91.

133. "This crucial point...implies the impossibility of any sharp separation between the behaviour of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear." APHK, pp.39-40; cf. pp.30,47,52, 98, and ATDN, pp.11,15.

134. e.g. APHK, pp.73,90.

135. e.g. APHK, pp.40,51,90,99.

136. e.g. APHK, pp.98,99. This feature has been exploited by J.Bub ("Hidden Variables, etc.") and D.Bohm ("On Bohr's View, etc.").

137. e.g. Essays, p.61.

138. e.g. APHK, pp.73,89,90,98.

139. These "atomic objects" include atoms, electrons, photons, etc.

140. "The characteristic new feature in quantum physics is merely the restricted divisibility of the phenomena, which for unambiguous description demands a specification of all significant parts of the experimental arrangement." Essays, p.92; cf. pp.4,60.

141. ATDN, p.19, APHK, pp.15,41,47, Essays, pp.5,12; see ch. 2.8 below.

142. "Can Quantum-Mechanical Description, etc.", pp.697-701, APHK, pp.40,72,90, Essays, pp.5,72. The frame of

reference here is the laboratory. On the problem of extending the notions of space and time into the quantum domain see B.Hoffmann, The Strange Story of the Quantum, New York, 1959, pp.196-199; and E.J. Zimmerman, "The Macroscopic Natúre of Space-Time", Am.J.Phys. 30, 1962, pp.97-105.

143. APHK, pp.5,7,26,30, "Newton's Principles, etc.", p.60.

144. "The Quantum Postulate, etc.", pp.580,582 = ATDN, pp. 54,60, APHK, p.52. N.B. Momentum and energy belong to the wave-mode because they are directly related to wavelength and frequency in quantum mechanics by the deBroglie and Einstein relations; cf. C.F.von Weizsäcker, The World View of Physics, London, 1952, pp.32-33.

145. APHK, pp.78-79,80,91-92; cf. A.Petersen, "The Philosophy of Niels Bohr", p.11.

146. "Can Quantum-Mechanical Description, etc.", pp.699,701; cf. "The Quantum Postulate, etc.", p.580 = ATDN, p.54, APHK, p.51, "On the Notions of Causality and Complementarity", pp.316-317; contrast J.von Neumann, op.cit., pp.419-420, and W.Heisenberg, Physics and Philosophy, New York, 1958, pp.55-57.

147. APHK, pp.40,72,90,99. M.Sachs misses this point in his "Positivism, Realism, and Existentialism in Mach's Influence on Contemporary Physics", Phil.Phen.Res. 30, 1970, p.405.

148. "This necessity of discriminating in each experimental arrangement between those parts of the physical system which are to be treated as measuring instruments and those which constitute the objects under investigation may indeed be said to form a principle distinction between classical and quantum-mechanical description of physical phenomena." "Can Quantum-Mechanical Description, etc.", p.701.

149. "For the instruments cannot be included in the investigation while they are serving as means of observation." "Light and Life", p.423; cf. Essays, p.5. I have chosen the symbols A,B, and C to correspond with J.McIntyre's "revelation model" - "A reveals B to C" (The Shape of Christology, Philadelphia, 1966, p.146).

150. "Can Quantum-Mechanical Description, etc.", p.698. "Accordingly, an independent reality in the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observation." "The Quantum Postulate, etc.", p.580 = ATDN, p.54.

151. Similarly the analysis of the structure of a tool excl- the free exercise of its function. This complementarity of function and structure in the use of tools has a close parallel in the tagmemic analysis in linguistics

(see W.A.Cook, Introduction to Tagmemic Analysis, London, 1969, pp.5-9). For instance, an expression like "the short man" can be treated either functionally as the subject (or object) of a larger unit or else structurally as a noun phrase which is composed of smaller units (limiter, modifier, and head). Hence function and structure of a given unit relate to different grammatical levels in linguistics as they to different ontological levels in physics. Of course, in grammar itself these levels coexist, but in actual speech they appear under mutually exclusive conditions; "the short man" constitutes a single stress unit when it functions as the subject of a longer clause, but it is subdivided into two or three stress units when it is isolated as a structure in its own right. Hence the shift from functional mode to structural mode involves a phonetic change in the unit itself and is not just the result of a shift in the focus of our attention from one level to another. Note that since function is complementary to structure in this sense, it cannot be entirely eliminated from science, even in physics. Hence the logic of complementarity conflicts with the aims of traditional structuralism; see e.g. J.Piaget, Structuralism, London, 1968, pp.69,102,118,142.

152. "Indeed, strictly speaking, the conscious analysis of any concept stands in a relation of exclusion to its immediate application." ATDN, p.96; cf. p.20, and APHK, p.52.

153. "We all know the old saying that, if we try to analyze our own emotions, we hardly possess them any longer..." APHK, p.27; see ch.3.3 below.

154. "...that harmony which is experienced as free will and analyzed in terms of causality." ATDN, p.24; see ch.3.3 below.

155. "Light and Life", p.458, "Causality and Complementarity", p.296, APHK, pp.9,76; see ch.3.2 below.

156. "...the unambiguous use of the concept of stationary states stands in a similar relation of complementarity to a mechanical analysis of intra-atomic motions as do light quanta to the electromagnetic theory of radiation." APHK, pp.6-7; cf. ATDN, pp.23,77-78.

157. contra A.Petersen who claims that Bohr gradually purged his philosophy of ontological ideas; see Quantum Physics and the Philosophical Tradition, pp.163,180.

158. "The Quantum Postulate, etc.", p.587 = ATDN, p.81; cf. "Causality and Complementarity", p.294, APHK, p.6, and Essays, pp.2,11,34,84. From the standpoint of classical mechanics and electrodynamics all atoms should collapse instantaneously; the electrostatic attraction between the positive nucleus and the negative

electrons rules out a static equilibrium configuration, and if the electrons should revolve around the nucleus like little (charged) planets they would radiate away their energy and spiral rapidly into the nucleus. Quantum theory avoids this dilemma by treating the electrons as standing waves rather than particles.

159. "...any imaginable procedure aiming at the coordination in space and time of the electrons in an atom will unavoidably involve an essentially uncontrollable exchange of momentum and energy between the atom and the measuring agencies, entirely annihilating the remarkable regularities of atomic stability for which the quantum of action is responsible. Conversely, any investigation of such regularities, the very account of which implies the conservation laws of energy and momentum, will in principle impose a renunciation as regards the space-time coordination of the individual electrons in the atom." APHK, p.19; cf. "The Quantum Postulate, etc.", p.587 = ATDN, pp.78-79, and Essays, pp.5,11,63.

160. "...the complementary relationship between the stability properties of the atoms themselves and such behaviour of their constituent particles as allows of a description in terms of space-time coordination." APHK, p.21; cf. p.85, ATDN, pp.23,78, and C.F.von Weizsäcker, op. cit., pp.53-54.

161. "The Quantum Postulate, etc.", p.580 = ATDN, pp.54-55.

162. ATDN, p.119; cf. "Newton's principles, etc.", p.60, "On the Notions of Causality and Complementarity", p.318, and APHK, pp.20,81.

163. For a rather confusing analysis, see K.M.Meyer-Abich, op.cit., pp.185-186.

164. See ch.1.4, above.

165. e.g. The Tacit Dimension, pp.9-10, and Knowing and Being, London, 1969, pp.235-236.

166. ibid; cf. Polanyi's distinction between subsidiary awareness and focal awareness (Personal Knowledge, pp.55-56, Knowing and Being, p.128) and between tacit knowledge and explicit or articulate knowledge (Personal Knowledge, pp.87,317, Knowing and Being, p.144); cf. Marcel's distinction between "pensée pensante" and "pensée pensée" (Du Refus à l'Invocation, Paris, 1940, pp.21-22; cf. R.M.Zaner, The Problem of Embodiment, The Hague, 1964, pp.6-7); and Tillich's distinction between "receiving knowledge" and "controlling knowledge" (Systematic Theology, Vol.1, London, 1953, pp.109f).

167. e.g. The Tacit Dimension, pp.9-11,16.

168. Polanyi attempts a transition from his epistemological considerations to an ontological structure but in effect he reduces ontology to epistemology; see _ibid_, p.13.

169. _Personal Knowledge_, pp.55-56, _The Tacit Dimension_, pp. 12-13, and _Knowing and Being_, p.127.

170. _ATDN_, p.99. Although it only appears once in the literature, this illustration was often used by Bohr in conversation; see P.A.M.Dirac, "The Versatility of Niels Bohr", in S.Rozental et al., _op.cit._, p.306; and O.Klein, _loc.cit._, p.93.

171. e.g. _APHK_, p.10, _ATDN_, p.24.

172. e.g. _Knowing and Being_, pp.219-220,235-236,237-238.

173. "...strictly speaking, it is not the emerged higher form of being, but our knowledge of it, that is unspecifiable in terms of its lower level particulars." _Personal Knowledge_, pp.393-394; cf. pp.390-393.

174. cf. the possibilities of observation and definition discussed in ch.1.3, esp. fn.66.

175. _The Tacit Dimension_, pp.41,45.

176. _ibid_.

177. See fn.123, above.

178. See ch.2.3 below.

Chapter 2

Bohr's Use of Complementarity in Atomic Physics

> "...complementary modes of thought and complementary descriptions of reality are an old, long-enduring part of our tradition. All that the experience of atomic physics can do in these affairs is to give us a reminder, and a certain reassurance, that these ways of talking and thinking can be factual, appropriate, precise, and free of obscurantism." J.R.Oppenheimer, Science and the Common Understanding, p.83.

Before we examine the relationship of complementarity itself, we should clarify what the terms are between which the relationship is supposed to hold. A survey of Bohr's usage of the concept shows a bewildering variety of terms which seem to be used interchangably even within the limited scope of atomic physics.[1] Most frequently Bohr speaks of complementarity between two types of aspects of phenomena,[2] or kinds of information[3] or of experiences[4] or of observations[5] or of evidence[6] obtained under mutually exclusive experimental conditions and visualizable by mutually exclusive ideas.[7] In the same phenomenalist style, he speaks of complementarity between pictures of the phenomena,[8] or between modes[9] or features[10] or aspects[11] of description, or between aspects of well-defined knowledge of objects.[12] In a more rationalist vein there is complementarity between different classical concepts,[13] between the ideas of wave and particle,[14] between the Schrödinger wave mechanics and the Heisenberg matrix mechanics,[15] between the definition of space and time and the definition of momentum and energy,[16] between "space-time coordination" and the dynamical conservation laws ("the claim of causality"),[17] between the applicability of the concept of stationary states and the mechanical analysis of intra-atomic motions,[18] and hence between the viewpoints of chemistry and physics.[19] But the structure of these observations and descriptions and concepts simply reflects the structure of nature. Hence there is complementarity between the undulatory and corpuscular character of light,[20] between the spatial continuity of light propagation and the atomicity of light absorption (the photoelectric effect),[21] and between the stability features of atoms and molecules and the space-time behaviour of their constituent particles.[22] In general, therefore, we may speak of a "wave-mode", in which momentum and energy are well-defined, light propagates and atoms are stable, and a "particle-mode", in which space-time location is well-defined, but light is absorbed (or emitted) and atoms are unstable.[23] Then what exactly is the relationship between these two modes of physical nature?

Bohr's first use of the term "complementarity" suggests that the <u>basic idea</u> is a relationship between two equally-important sectors of a total description which somehow exclude each other in reality.[24] However, Bohr never gave an explicit definition of the term. In fact, in his very next paper he temporarily abandoned the term "complementarity" in favor of "reciprocity",[25] but he later returned to "complementarity" explaining that it "may perhaps be more suited also to remind us of the fact that it is the combination of features which are united in the classical mode of description but appear separated in the quantum theory that ultimately allows us to consider the latter as a natural generalization of the classical physical theories."[26] But Bohr continued to regard the term as being somewhat artificial and pointed out that it was not taken from our everyday language.[27]

In view of these points, we cannot derive the meaning of complementarity from its ordinary usage in relation to complementary angles, complementary colors, etc., and only a complete survey of Bohr's use of the term will provide an adequate definition.[28] I find eleven distinct points in Bohr's usage which cannot be reduced to one another even though some are closely related. Together these points map out the logic or structure of the complementarity relationship.[29]

2.1. Unity:

The complementary modes belong to <u>one and the same object</u>.[30] What appears to be a wave under some circumstances and a particle under others is in fact the same physical entity. In contrast, this could not be said of dualistic relationships like those between male and female, "yin" and "yang",[31] or good and evil. Hence, complementarity is to be distinguished from <u>duality or dualism</u>,[32] and the popular phrase, "wave-particle duality", is technically a misnomer.[33]

2.2 Common Properties:

Going along with the unity of the modes is the fact that they share some common properties.[34] In the non-relativistic (electron-volt) domain appropriate to atomic phenomena, these are rest mass, electric charge, and spin angular momentum.[35] However at higher energies, comparable to the rest-mass energy of the particles (millions of electron-volts), suitable for the exploration of atomic nuclei, the particles themselves become unstable and the definition of their mass and charge is possible only within the stable "wave-mode" (i.e. not during the localized interaction of particles).[36] Even for the constituents of stable nuclei there is an uncertainty of mass and charge due to the highly-localized "strong-force" interaction and the continual exchange of virtual mesons. In this case the "common properties" would be the baryon (or atomic) number, hypercharge, isotopic spin, spin angular momentum and parity.[37] These are considerably more abstract than rest mass and electric charge. At even higher energies, as yet unexplored, there may be an even more abstract set of "common properties" between the modes or perhaps none at all.[38]

It is tempting to treat these common properties as the "invariants" of a "complementarity transformation", thus imbuing them with a greater or deeper degree of reality than the "conjugate properties" which are not shared by the two modes.[39] For instance, Max Born regards the isolation of a set of invariant common properties as the only final assurance that a physical entity is objectively real.[40] But what would then happen to objective reality if at some higher energy no common properties could be found at all? It would be a mistake to identify objectivity with invariance.[41] In fact, it would simply be a repetition of the "fallacy of misplaced concreteness" which Whitehead cites in connection with the seventeenth century distinction between primary and secondary qualities.[42] For example, Margenau has drawn this very distinction between what he calls "possessed observables", like mass and charge, and "latent observables", like position and momentum, and he ends up with a complete bifurcation between "physical reality", which is lawful but unobservable (cf. _mundus intelligibilis_), and "historical reality", which is observable but completely unpredictable (cf. _mundus sensibilis_).[43] In other words, for Margenau, this table in front of me, this particular table, is an historical but not a physical reality!

In any case, the quest for invariance is inconsistent with Bohr's own philosophy. For Bohr, there is no thing-in-itself independent of its particular environment.[44] So the modes of reality are not illusory just because they are relative; they do not correspond to "secondary qualities". To use a distinction made by Barth, they are "modes of existence" _within_ which the object exists, rather than modes of an object _behind_ which the object exists as a distinct essence.[45] _The object is fully present in each of its modes_. This brings us to the third point of the logic of complementarity.

2.3 Individual Completeness:

Each mode is _complete in itself_ in the sense that the object may be completely described, _in a given situation_, in terms of the appropriate mode without any explicit reference to the alternate mode. Only as the situation changes does the alternate mode enter the picture. For instance, the propagation and interference of light can be completely accounted for by the electromagnetic wave theory while the interaction between radiation and matter can be completely understood in terms of the concept of the light quantum introduced by Einstein.[46]

Another way of putting this is to say that each mode is well-defined in the sense that given a particular experimental situation (e.g. light propagating in free space), the mode of existence is unambiguously determined (i.e. the wave-mode) even though the physical state of that mode (frequency, wave-length) is left undetermined.[47]

The condition of completeness distinguishes complementarity from the relationship of orthogonality or dimensionality or modality. It is often said that complementary modes represent the same object as seen from different viewpoints or perspectives.[48] One must somehow synthesize the various projections or dimensions in order to get a complete picture. However, this relationship would not qualify as complementarity in Bohr's sense because the object is never completely described by any one of its dimensions. In orthogonality the object exists 'behind' the modes rather than 'within' them, hence the modes are modes of the object rather than modes of the object's existence.

2.4 Coexhaustiveness:

The two modes are coexhaustive in the sense that together they are sufficient to exhaust all possible knowledge of the object under all possible conditions.[49] In other words, the object is never known and never exists other than in one of its two modes; there is no third mode.[50]

It was specifically due to this coexhaustiveness that Bohr regarded complementarity to be a rational generalization of the classical principle of causality,[51] and hence to satisfy the correspondence principle.[52] In classical physics the evolution of a physical body is completely determined by its position and momentum at any instant of time. In quantum physics this determinism breaks down because position and momentum can never be defined simultaneously, yet both are included in the complementary description (in the particle and wave modes, respectively), and there is no loss of generality.

2.5 Equal Importance:

The two modes are equally essential,[53] equally important,[54] equally indispensable,[55] and equally necessary[56] in the sense that both together are necessary (as well as sufficient) for an exhaustive treatment of the atomic object.[57] It follows that the modes are mutually irreducible; that is, one cannot be analyzed in terms of the other,[58] and one is just as real as the other.[59]

The condition of equality clearly distinguishes complementarity from equivalence or supplementarity, a relationship with which it is often confused. It is often said, for instance, that the wave and particle pictures (or representations) are two alternate, equivalent models for atomic objects, and that one can transform from one to the other at will.[60] This is true only if the terms "wave" and "particle" are taken in their strictly classical senses: a "wave" is an oscillation of any form in space, and a "particle" is a point mass with well-defined position and momentum. Then the wave and particle pictures are equivalent for several reasons: (1) According to the Einstein-de Broglie relations, the momentum of a particle is inversely proportional to the wavelength of an associated wave and the energy of a particle is directly proportional to the frequency of the wave. Hence one can transform from particle-language (momentum, energy) to wave-language (wavelength, frequency) simply by dividing or multiplying by a constant (Planck's constant).[61] (2) As de Broglie first showed, a particle can be represented by a wave-group such that the velocity of the particle is equal to the group-velocity of the waves.[62] (3) Atomic structure can be treated either in the Schrödinger formalism in terms of standing waves, or in the Heisenberg formalism in terms of position and momentum operators subject to commutation rules (the "uncertainty principle"). As Schrödinger, himself, showed the two formalisms are mathematically equivalent even though they are conceptually incompatible and one can transform from one to the other.[63] (4) Any wave function (the mathematical representation of Schrödinger's standing waves) can be expanded mathematically either in terms of an indefinite set of simple harmonic waves (a Fourier series) or in terms of an infinite set of possible particle positions (Dirac delta-functions) as Born showed by his theorem of spectral decomposition.[64] (5) In quantum field theory one treats various <u>force fields</u> as if they were due to the exchange of <u>virtual particles</u>: photons for the electromagnetic field, mesons for the strong-force field, "W-particles" for the weak-force field, and "gravitons" for the gravitational field.[65] Since this transformation is accomplished by the purely formal process of "second quantization", the field theory and the quantized field theory are mathematically equivalent.[66] In this sense it is true that particles and fields are equivalent (though incompatible) pictures which can be transformed into one another.[67] But this is not complementarity in Bohr's sense because both pictures are not needed; one could choose either one and work exclusively within it. Hence it is a relationship of supplementarity, not complementarity.

However, whichever picture one chooses, one finds an alternation between two complementary modes.[68] In the de Broglie-Schrödinger wave-picture one starts with a simple harmonic wave with well-defined frequency and wave-length propagating in free space (the "wave-mode"), but this wave collapses to a point (represented by a superposition of waves or else a single Dirac delta-function) when it interacts with matter (the "particle-mode").[69] Similarly, in the Heisenberg particle-picture one has either a well-defined momentum and energy when propagating in free space ("wave-mode") or a precise position at a particular instant of time when the particle interacts or "collides" with another particle ("particle-mode"), but not both at the same time.[70] Similarly, in quantum field theory one has either well-defined field variables or a definite number of "particles", but both cannot be defined at the same time.[71]

The following table briefly summarizes the relationship between complementarity (wave and particle modes) and supplementarity (wave and particle pictures).

	complementary	wave-mode (in free space)	particle-mode (interaction)
supple-mentary	wave-picture	simple harmonic wave wavelength, freq.	superposition of waves
	particle-picture	momentum, energy	position, time

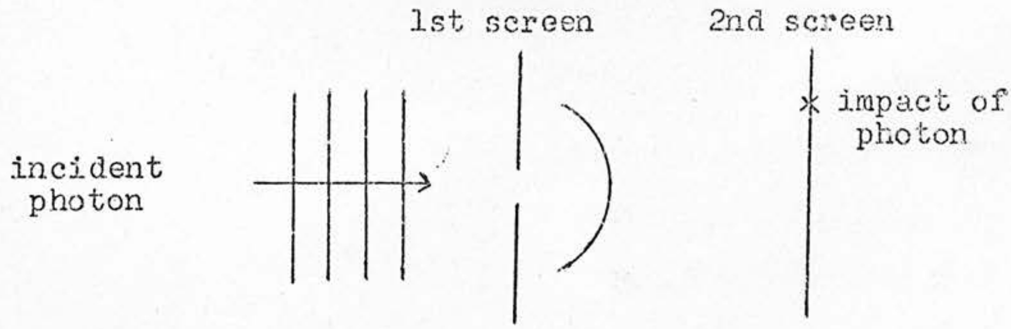
Moving from top to bottom is a purely formal transformation (supplementarity); moving from right to left represents the evolution in time (complementarity). This brings us to the next point.

2.6 Alternation:

The temporal evolution of the physical entity proceeds by a continual alternation between one mode and the other as the entity passes from one situation to another. The example most frequently cited is that of single-slit diffraction:[72] a photon (or electron) is fired at a screen with a narrow slit (from a large distance). If it passes through the slit it is diffracted and finally it impinges upon a second screen behind the first. If it doesn't pass through the slit it is absorbed by the first screen.

From the viewpoint of complementarity the situation is as follows: before the photon arrives at the first screen it is a plane wave with well-defined frequency and wavelength.

Single-slit Diffraction



When it interacts with the first screen, whether by absorption or diffraction, it 'becomes' a particle with well-defined position (the time of diffraction can be determined by using a shutter over the slit). If it passes through the slit it is diffracted and propagates from one screen to the other as a spherical wave,[73] and when it hits the second screen at some particular point it 'becomes' a particle again. Hence the photon (or electron) adjusts to each new situation by changing its mode of existence. Incidentally, this "experiment" clearly illustrates Bohr's distinction between the possibilities of definition and the possibilities of observation. The photon is only 'observed' when it hits one of the screens. However, its modal existence is defined at all points of its evolution because the experimental arrangement is completely specified.

It is possible to associate the relationship of kinematical (space-time) and dynamical (momentum-energy) variables with the philosophical relationship of "being" and "becoming".[74] For free particles the wave-mode applies to propagation in free space (cf. "becoming") and the particle-mode applies to instantaneous location (cf. "being") as in the single-slit diffraction experiment just described. However, the correlation is just the reverse for the evolution of an atom: the wave-mode corresponds to the stationary states of the atom ("being") and the particle-mode corresponds to transitions between these states ("quantum jumps", "becoming").[75] Therefore, one should not take these connections too seriously. Rather, one should regard either mode as an interval of becoming between the states of being of the other mode. In relation to the single-slit experiment, for instance, the spherical wave represents a transition from a particle located at the slit of the first screen to a particle located at a point on the second screen. Alternatively, the particle at the slit of the first screen represents a transition from a plane wave to a spherical wave. The relationship between the two modes is strictly symmetrical in this regard.

2.7 Coinherence:

If the two modes pertain to a single entity and that entity evolves by an alternation between the modes, then there must be some positive connection like an "interpenetration" or "coinherence" between the modes. Bohr says very little about this connection, and what little he does say is not entirely definitive. In his treatment of the single-slit experiment, for instance, he speaks of "the train of plane waves corresponding to the state of motion of the particle".[76] Since there is no permanent particle embedded in the wave for Bohr,[77] I take this to mean that the particle exists as a potentiality in the wave in the sense that the wave is capable of "collapsing" and producing a particle when it interacts with the screen.[78] Bohr goes on to speak of "the diffraction of the wave connected with the motion of the particle" as it penetrates through the slit in the first screen.[79] Since this diffraction consists of the "collapse" of the plane wave on one side of the slit (producing a particle at the slit) and the expansion of a new spherical wave on the other side, there is actually no single wave at the instant of diffraction. However, the wave exists as a potentiality in the particle as it passes through the slit in the sense that the particle is capable of "expanding" and producing a wave once it enters free space.[80] Finally, Bohr says that "the state of motion of the particle is represented by a spherical wave train" after it emerges from the slit,[81] again meaning that it exists as a potentiality within the spherical wave though it is not actualized until it impinges upon the second screen. Hence, the two modes of an atomic object might be said to _coinhere_ _or_ _interpenetrate_ each other, and in this sense an atomic object is _both_ a wave _and_ a particle (or, in the case of an atom, a group of particles).[82]

A corollary of this coinherence or interpenetration is that there is _inter-participation_ or _co-operation_ between the modes. Whenever the actual mode does something, the potential mode participates in and cooperates with that action since it exists as a potentiality in the actual mode during the action. Thus Bohr speaks of the "motion of a particle" in free space (wave-mode actual), on one hand, and of "waves passing through the hole [i.e. the slit]" (particle-mode actual), on the other.[83]

Note that in each of the examples given the capability or potentiality in question is only one of response to a change in the physical environment and not an intrinsic capacity. This is best seen in the case of atomic structure: a stable atom is only capable of producing "free" particles in response to the stimulating effect of radiation (or collisions with free electrons).[84] Hence it would not have this capability in intergalactic space where the density of radiation is negligible. Conversely, the constituent particles of an atom are only capable of forming a stable atom in the absence of disturbing effects. Hence they would not have this capability in the interior of a star where the radiation is very intense. Therefore, this capability or potential must always be viewed in relation to the environment.[85]

2.8 Mutual Exclusiveness:

In spite of the element of coinherence, each mode is complete in itself (condition 3) and, moreover, the two modes are mutually exclusive in the sense that they are conceptually incompatible and cannot be combined into a single picture. In the first instance, this incompatibility pertains to the experimental arrangements[86] or to the conditions necessary for the unambiguous application of classical concepts,[87] especially the concepts of space and time, on one hand, and the dynamical conservation laws, on the other.[88] But it also applies to the phenomena themselves,[89] to the kinds of information or evidence obtained about the behaviour of atomic objects,[90] to the ideas (taken from classical physics) by which such information can be visualized,[91] and to the properties of atomic objects[92] and the laws which appear under different experimental conditions.[93] Hence there is a relation of mutual exclusion between the corpuscular and undulatory characters of light (or matter),[94] between "space-time coordination" and the "claim of causality",[95] and between the application of the concept of stationary states to an atom and the description of the behaviour of the of the constituent particles.[96] But however incompatible these opposing aspects of quantum phenomena may be, they can never be brought into direct contradiction with each other because the experimental conditions required for their very definition are mutually exclusive.[97] In short, the two modes exclude each other in thought, experience and in reality.

The condition of mutual exclusiveness again distinguishes complementarity from the relations of orthogonality (modality) and equivalence (supplementarity). Two equivalent pictures may exclude each other in thought or even in experience, but they coexist in reality. For example, the electromagnetic force is both a field and an exchange of virtual photons even though we can only use one of these pictures at a time. Similarly, two orthogonal dimensions or projections coexist in an object even though we may only be able to observe or imagine one at a time. However, it is sometimes possible to adopt an intermediate viewpoint from which both dimensions are partly visible. Hence orthogonal dimensions are not strictly exclusive even in thought and experience.

2.9 Conjugate Properties - Reciprocity:

At least some of the properties of an atomic object are not held in common by the two modes; they are well-defined in, and characteristic of, only one of the modes, not the other. These properties occur in conjugate pairs like position amd momentum, or time and energy.[98] For clarity, we shall refer to the characteristic properties of a given mode as the <u>explicit properties</u> of that mode. The properties that are neither common nor characteristic are the <u>implicit properties</u> of that mode in the sense that they are ill-defined in that mode but well-defined in the alternate mode which inheres within it. The explicit properties of one mode are the implicit properties of the other, and vice versa. For instance, position and time are explicit properties of the particle-mode and implicit properties of the wave-mode. The reverse holds for momentum and energy.

	position time	momentum energy
particle-mode	explicit	implicit
wave-mode	implicit	explicit

As the atomic object alternates between its two modes, the (complementary) modes alternate between being actual and potential and the conjugate properties alternate between being explicit and implicit.

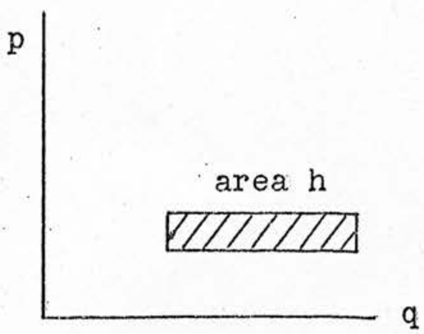
This leads us to the Heisenberg uncertainty principle in such a way that it is seen to be an integral part of the logic of complementarity. Since only one mode can be actualized at a time (mutual exclusiveness), it follows that only one of a pair of conjugate properties can be explicit at a time. There can be no simultaneous definition or measurement of the explicit properties of both modes.[99] The unambiguous definition (or precise measurement) of one implies the exclusion or "renunciation" of the unambiguous definition of the other leaving a gap or "rupture" in the corresponding description.[100] In the Heisenberg formalism this reciprocal relation is symbolized by a set of commutation rules: the mathematical operators corresponding to two conjugate properties do not commute with each other.[101] From these rules Heisenberg developed his famous "indeterminacy relations": there is a reciprocal latitude or uncertainty between two conjugate properties; the better defined one is, the less well-defined the other, and vice versa.[102] The product of the uncertainties is on the order of Planck's constant (the quantum of action, h).[103] Bohr referred to this as a relation of reciprocity between the two modes, or a reciprocal symmetry between their explicit properties.[104] Heisenberg's indeterminacy (or uncertainty) relations, he said, gave quantitative or symbolic expression to the idea of reciprocity.[105]

One consequence of the uncertainty principle is that there is real becoming in the evolution of an atomic object. The alternation between modes is not simply a repetitious cycle and the evolution is not just the unfolding of a preexistent plan because the state of the potential mode, that is, the value of its explicit property, is not predetermined by the state of the actual mode even given the experimental conditions.[106] The term "indeterminism" is perhaps misleading because the classical ideal of determinism is only limited by the magnitude of Planck's constant, a very small number by everyday standards.[107] Complete determinism would correspond to a zero-value of Planck's constant, and complete indeterminism would correspond to an infinite value. Hence "limited determinism" or "partial indeterminism" would better characterize the situation. Nature is allowed just enough "elbow room", so-to-speak, for real becoming.[108]

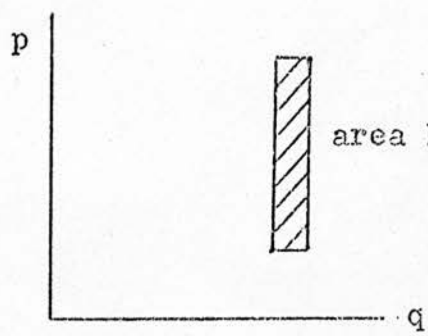
Two further consequences can only be briefly mentioned: (1) The evolution of atomic objects is governed by <u>statistical laws</u>, as first demonstrated by Max Born.[109] These are not the result of ignorance as they are in the case of life insurance statistics or betting odds;[110] they are inherent in the nature of reality.[111] Like the uncertainty principle, the use of statistics has a positive as well as a negative side; it represents definite laws and regularities in the quantum domain even though it falls short of the classical ideal of complete determinism. Thus it represents a rational generalization of the principle of causality in Bohr's terminology.[112] (2) The evolution of atomic objects is <u>irreversible</u> since their interrelation with the macroscopic environment is holistic and cannot be analyzed in mechanical terms.[113] Therefore an atomic object will not usually return to its initial state if it is turned around and sent back into its previous environment.[114] Bohr frequently spoke of this irreversibility as inherent in the very concept of "observation", i.e. the specification of the experimental conditions, and illustrated it by the irreversibility of amplification processes that take place in any act of (quantum) measurement.[115]

The results of this section can be brought together into a rather simple picture. A set of (uncommon) properties that may be specified simultaneously constitutes a four-dimensional space. For instance, the set of ordinary space and time coordinates constitutes a four-dimensional geometric or <u>kinematical space</u>, and the set of momentum and energy coordinates constitutes a (conjugate) <u>dynamical space</u>. When an atomic object exists in the wave-mode, it is represented by a point in dynamical space (well-defined momentum and energy) and by a complete blur in kinematical space (a wave is continuous over all space and time). When the atomic object transforms into its particle-mode, the point in dynamical space spreads out into a blur and the blur in kinematical space collapses to a point.[116] The fact that one of the two conjugate spaces is always filled with a blur illustrates the inherent uncertainty of definition, and the fact that the blur may collapse to any point within its volume illustrates the lack of complete determinism.[117]

An even further simplification can be made by combining these two conjugate spaces into a single eight-dimensional "phase space". Here the atomic object is represented by a phase cell of (approximate) volume h^4 (Planck's constant raised to the fourth power, once for each pair of conjugate properties). The volume of the cell is constant, but the shape changes from one mode to the other. In the wave-mode it is very narrow in its momentum and energy dimensions and very broad in its space and time dimensions. When it converts to the particle-mode it becomes very narrow in its space and time dimensions and very broad in its momentum and energy dimensions. The sketches below illustrate this oscillating phase cell in just one pair of its conjugate properties; a position coordinate (q) and a momentum coordinate (p).



wave-mode



particle-mode

The volume of the cell is invariant. The shape of the cell is determined by the experimental conditions (in accordance with the modality), but the location of the cell is only statistically determined.[118] Briefly this scheme summarizes the nine points of the logic of complementarity we have covered so far. Note that the relationship between the modes thus far is completely symmetrical.[119]

2.10 Emergence:

There is also an important element of asymmetry between the modes in that one of them, the wave-mode, allows a greater degree of <u>stability and regularity</u> than the other as is evident from the contrast between stable atoms and free particles.[120] In fact, it was just the impossibility of explaining atomic stability in classical physics that led to the development of quantum theory and the principle of complementarity in the first place.[121] The stable wave-mode accounts for most of the characteristic properties of matter treated in physics and chemistry:[122] atomic processes,[123] characteristic atomic spectra,[124] homopolar chemical bonds,[125] and chemical reactions.[126] Therefore, the principle of complementarity leads to a unification of the disciplines of physics and chemistry.[127] As Bohr put it, they represent two complementary viewpoints, equally indispensable for the comprehension of the laws of nature.

Clearly there is a greater degree of wholeness, unity and coordination in the wave than in the particle-mode. We could think of them as representing <u>the whole</u> and <u>the parts</u>, respectively, provided we remember that the difference is not simply the result of a "gestalt switch", a shift in the focus of our attention from the pattern to the individual features, but rather a complete transformation in the object itself correlated with a change in its objective situation.[128] The wave-mode exhibits greater wholeness and stability because it involves the definition of momentum and energy and hence satisfies the "claim of causality". But this definition is only possible in the absence of strong interference from the environment. Hence the greater wholeness and stability of the wave-mode are contingent upon a greater degree of <u>independence and integrity</u> so that the conservation laws are allowed to operate freely. Such freedom is incompatible with close observation or control of the constituent particles, as we have seen.[129]

2.11 The "Pointing" Relationship:

Parallel to the ontological asymmetry of emergence there is an epistemological asymmetry between the two modes as between the analysis of A (here an atomic object) and the immediate application of A or between A-analyzed and A-applied. As we have noted, Bohr regarded this relationship to be the most general manifestation of complementarity.[130] It implies that the wave-mode cannot be known directly or specifiably like the particle-mode, but only indirectly and tacitly as the laws of conservation and the principle of causality are allowed to function freely.[131] This does not mean that the wave-mode cannot be observed at all: the momentum of an atomic object can be measured by the Doppler-shift of scattered light provided that the wavelength of the light is sufficiently long (and hence the momentum of the light sufficiently small) that it does not appreciably disturb the momentum balance of the wave-mode, and the observed Doppler-shift can be interpreted as a true (though indirect) measure of the object's momentum.[132] Also, the various stability properties mentioned above are all indirect evidence of the existence of stationary states. But the constraint remains that in order to know the wave-mode we must respect its integrity, use it in accordance with its proper function, and refrain from analyzing it as a space-time structure. To use Polanyi's idiom, we must "indwell" the atomic object in order to know it (tacitly) as a wave just as we must indwell a stick in order to know it as a probe.[133]

In addition to the epistemological asymmetry between the modes and corresponding to it, there is an ontological connection which is more difficult to formulate. When we are confronted with an unfamiliar object our first reaction is usually to analyze it in terms of structural categories. According to the principle of complementarity we might never exhaust the object by such an analysis because there might be another mode of its existence which cannot be analysed in terms of the first (equal importance). In this case, the second mode exists as a potentiality within the first (coinherence), and we are invited, so to speak, to discover the new mode by indwelling the object, using it in accordance with its proper function and learning to know it tacitly as well as specifiably. Thus when presented with an unfamiliar artifact for the first time we begin by handling it and examining its structure, and as our attention is drawn to its most peculiar features and their relationships we are often able to intuit the function of the artifact. Similarly, when physicists first explored the atom they analyzed it in terms of space-time pictures (the Rutherford "planetary model"), and only gradually learned to understand it in terms of stationary states and wave mechanics. In each case the structure suggests or points to the function even though we cannot reduce one to the other. This ontology is presupposed by Bohr's contrast between analysis and application though never explicitly stated by Bohr himself.

We have seen that Bohr's concept of complementarity is both complex and highly specific. Of the eleven points discussed, some might be grouped together under a single composite heading while others might be subdivided into two or more distinct points depending on one's individual taste.

The fact is that it is impossible to define an organic concept by any analysis or enumeration of distinct points. The only way to fully understand the concept is through its use or application. Nonetheless, an analysis of this sort may provide the guidelines to point us in the proper direction.

Footnotes: Chapter 2.

1. For a more lengthy analysis of Bohr's use of the term 'complementarity' in atomic physics see E.Scheibe, op. cit., pp.30-35.

2. e.g. APHK, pp.19,40,41, 47,90,99, and Essays, pp.19,25,60.

3. "Causality and Complementarity", p.291, APHK, p.26.

4. APHK, pp.27,30,74.

5. "Causality and Complementarity", p.296.

6. APHK, p.40, and Essays, p.92.

7. Complementary uncertainties or restrictions on the measurability of electric and magnetic fields are discussed in a paper by N.Bohr and L.Rosenfeld; "Zur Frage der Messbarkeit der Elektromagnetischen Feldgrössen", (Det) Kongelige Danske Videnskabernes Selskab: Mathematisk-fysiske Meddelelser 12 (No.8), 1933, pp.11,17,27,34,52, 56.

8. ATDN, pp.56,94, and APHK, p.5.

9. ATDN, p.10.

10. ATDN, pp.19,54.

11. "Can Quantum-Mechanical Description, etc.", p.699.

12. "On the Notions of Causality and Complementarity", p.314, "Physical Science and the study of Religions", p.387, and APHK, p.26.

13. "Can Quantum-Mechanical Description, etc", p.699.

14. ATDN, p.75, APHK, p.5.

15. "The Quantum Postulate, etc.", p.586 = ATDN, pp.75-76. Bohr associated the Schrödinger theory with the stationary states and the Heisenberg theory with transitions between the states; cf. "On the Notions of Causality and Complementarity", p.314. For a good comparison of the two theories see M.Jammer, The Conceptual Development of Quantum Mechanics, pp.271-272.

16. "The Quantum Postulate, etc.", p.587 = ATDN, p.78.

17. ATDN, pp.11,54,60,94.

18. ATDN, p.23, APHK, pp.6-7.

19. "Chemistry and the Quantum Theory of Atomic Constitution", J.Chem.Soc, 1932, Part 1, p.376. Bohr associated physics with the motion of (elementary) particles and chemistry with the properties of stable atoms; see ibid, pp.349,369, and below, ch.2.10.

20. "Causality and Complementarity", p.294.

21. APHK, pp.5,6-7; cf. "The Causality Problem in Atomic Physics", in New Theories in Physics, Paris, 1939, pp.15,23.

22. "Can Quantum-Mechanical Description, etc.", p.701, and APHK, pp.21,99.

23. e.g. ATDN, pp.113-114. Much confusion has arisen due to the fact that the "wave-mode" of light is associated with propagation in space and time while the "particle-mode" is associated with the photoelectric effect and the Compton effect and hence with the conservation of momentum and energy ("The Quantum Postulate, etc.", p.580 = ATDN, p.55). For instance, W.H.Austin associates space and time with the wave-mode and the conservation of momentum and energy with the particle-mode (op.cit., p.27). Even M.Born once made this mistake (Atomic Physics, London, 1962, pp.99-100). In fact, the definition of wavelength and frequency (and hence of momentum and energy) is essential to the idea of wave propagation. And, as Bohr explains, it is only in classical physics that momentum and energy can be defined in terms of space-time pictures; in general, they must be defined by means of conservation laws and cannot be assigned to a particular space-time location ("The Quantum Postulate, etc.", pp. 581-582 = ATDN, pp.58-60). It is true that some physicists have avoided ascribing a particle-mode to light (photons) because the absorption of light (the interaction of photons with matter) is its annihilation (e.g. W.Heitler, The Quantum Theory of Radiation, London, 1944, pp.63-64, and D.Bohm, Quantum Theory, pp.107-108). However, this annihilation is readily understood as a consequence of the theory of relativity; light travels at the speed of light in all inertial systems, hence it cannot have a rest frame. Moreover, the space-time location of a photon can be determined without its annihilation either by the scattering of another photon or by the use of a slit-shutter combination (see ch.2.6 below). Besides, if complementarity were abandoned for photons alone, then a unified treatment of all "particles" would be impossible (cf. M.Born and W.Beim, "Dualism in Quantum Theory", Physics Today 21 (No.8), 1968, pp.51-55). On the analogy of polarization of light and the spin direction of elementary particles see D.Bohm and Y. Aharonov, "Discussion of Experimental Proof for the Paradox of Einstein, Rosen, and Podolsky", Phys.Rev. 108, 1957, p.1073, and "Further Discussion of Possible Experimental Tests for the Paradox of Einstein, Podolsky and Rosen", Nuo.Cim. Series 10, 17, pp.973-974; E.P.Wigner, Symmetries and Reflections, Bloomington,

1967, p.53. For a recent review see M.O.Scully and M. Sargent III, "The Concept of the Photon", Physics Today 25 (No.3), 1972, pp.38-47.

24. "The very nature of the quantum theory thus forces us to regard the space-time coordination and the claim of causality, the union of which characterises the classical theories, as complementary features of the description, symbolising the idealisation of observation and definition respectively." "The Quantum Postulate, etc.", p.580 = ATDN, pp.54-55.

25. "Wirkungsquantum und Naturbeschreibung", Naturwis. 17, 1929, pp.483-486 (E.T. "The Quantum of Action and the Description of Nature", in ATDN, pp.92-101).

26. ATDN, p.19. This is a typical example of Bohr's tortuous style of writing.

27. "In the last resort an artificial word like "complementarity" which does not belong to our daily concepts serves only briefly to remind us of the epistemological situation here encountered, which at least in physics is of an entirely novel character." "Causality and Complementarity", pp.293-294. The concept of complementarity is not found in classical physics (except perhaps in thermodynamics; see ch.3.1 below), but individual terms of the complementary relation are taken from classical physics in accordance with the correspondence principle.

28. contra D.M.Mackay, "Complementary Descriptions", Mind 66, 1957, p.392, and "Complementarity II", Proc.Arist. Soc., Supplement, 32, 1958, pp.105,114.

29. To my knowledge no systematic attempt has previously been made to map out Bohr's logic in this way. Only a few of the eleven points listed here have previously been recognized, the most being given by T.R.Blackburn ("Sensuous-Intellectual Complementarity in Science", Science 172, 1971, pp.1003-1007). Blackburn's seven points correspond to six of the points listed here.

30. "Information regarding the behaviour of an atomic object obtained under definite experimental conditions may... be adequately characterized as complementary to any information about the same object obtained by some other experimental arrangement excluding the fulfilment of the first conditions." APHK, p.26; cf. ATDN, p.96.

31. When Bohr was awarded the Danish Order of the Elephant in 1947 he had to design a coat-of-arms to be placed in the church of Frederiksborg Castle at Hillerød. The design he chose was the ancient Chinese yin-yang symbol with the insignia, "Contraria sunt complementa", above (see illustration facing p.305 in S.Rozental et al., op.cit.). There was never any question, however, that the relation of complementarity could be visualized in this (or any other) manner.

32. A.van der Mensbrugghe distinguishes between "dualism" and "duality" in such a way that his "duality" is roughly equivalent to Bohr's "complementarity". See his From Dyad to Triad, London, 1935, esp.pp.14ff.

33. contra M.Born, Physics in My Generation, London, 1956, p.106, Physics and Politics, Edinburgh, 1962, p.57 fn., and Natural Philosophy of Cause and Chance, New York, 1964, p.105; see below ch.4.5.

34. It is important to realize that the existence of common properties is neither a necessary nor a sufficient condition for unity of substance (singleness of being). A caterpillar changes into a butterfly and thus maintains continuity of being, yet the two modes of being have few, if any, common properties (they differ in weight, color, shape, structure, etc.). On the other hand, any two electrons are identical, in fact, indistinguishable, due to their common rest mass, charge and spin.

35. "...an electron may be called a charged material particle, since measurements of its inertial mass always give the same result, and any transmission of electricity between atomic systems always amounts to a number of so-called unit charges." APHK, p.98. "...the ultimate electrical particles, beside their mass and charge, are endowed with a magnetic moment due to an angular momentum determined by the quantum of action." ATDN, p.88. Note: the basic unit of magnetic moment is known as the "Bohr magneton" in recognition of Bohr's early work on the quantum theory.

36. "Chemistry and the Quantum Theory, etc.", p.357, and "Causality and Complementarity", p.294.

37. See G.F.Chew et al., "Strongly-Interacting Particles", Sci.Am. 210 (No.2), 1964, pp.74-93.

38. In this case the ultimate complementarity would be between "invariants" (the properties of stable particles which give them identity) and "events" (space-time location limited to a single point) and hence between "particles" (or fields) and "interactions". Note: Heisenberg has suggested that there may be a universal "minimum length" of about 10^{-13} cm. (e.g. Physics and Philosophy, pp.164-165). This would simply set a lower limit on the possible precision of "space-time coordination"; cf. W.Yourgrau, "Some Problems Concerning Constants in Physics", in H.Feigl and G.Maxwell, eds., op.cit., pp.326-328.

39. The "invariance" in question is one of continual definition, not necessarily one of constant value, as the atomic object alternates between one mode and the other. In either case invariant means "invariable", not "objective" or "intrinsic" as in T.F.Torrance, "Newton, Einstein and Scientific Theology", Rel.Stud. 8, 1972, p.242.

40. M.Born, "Albert Einstein und das Lichtquantum", Naturwis. 42, 1955, p.430, Physics in My Generation, pp.105,160-161,187, and Physics and Politics, p.30.

41. cf. M.Bunge's criticism of Rosenfeld ("Strife About Complementarity", pp.9-12) and W.Yourgrau's criticisms of Planck, Einstein, Born and Heisenberg ("On the Reality of Elementary Particles", in M.Bunge, ed., The Critical Approach to Science and Philosophy, Glencoe, 1964, pp. 371-374).

42. Science and the Modern World, New York, 1967, pp.50ff.

43. "Reality in Quantum Mechanics", Phil.Sci. 16, 1949, pp. 297-301, The Nature of Physical Reality, New York, 1950, pp.3,175-176,327,418,452, "Advantages and Disadvantages of Various Interpretations of the Quantum Theory", Physics Today 7 (No.10), 1954, p.10, and Open Vistas, New Haven, 1961, pp.136,141,183; see below, ch.5.6.

44. See above, ch.1.5.

45. "God is completely the person He purports to be in His manifestation and gift of Himself to us. To hasten past Him who addresses us as Thou in a threefold confrontation according to the Biblical witness, can only be to hasten into the void." Church Dogmatics, I.1, ch.9,4, p.439. It seems that high-energy physics is "hastening into the void" in its endless quest for symmetry and invariance. The quest should go on, by all means, but the asymmetry and variance should not be regarded as less real than the other; or else we may completely bypass important aspects of reality in our haste; cf. A.N.Whitehead's "actual entities" or "actual occasions"; Process and Reality, New York, 1969, p.23.

46. "The Quantum Postulate, etc.", p.580 = ATDN, p.55; see A.Einstein, "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt", Ann.Phys. 17, 1905, pp.132-148.

47. "However great the constrast exhibited by atomic phenomena under different experimental conditions, such phenomena must be termed complementary in the sense that each is well defined and that together they exhaust all definable knowledge about the objects concerned." APHK, p.90. The further condition of coexhaustiveness is cited in this passage.

48. e.g. M.Born, Physics in My Generation, pp.160,187; C.A. Coulson, Christianity in an Age of Science, London, 1953, pp.20-33, Science and Christian Belief, London, 1958, pp.86-107, "The Similarity of Science and Religion", in I.G.Barbour, ed., Science and Religion, London, 1968, pp. 72,75; D.M.Mackay, "Man as Observer-Predictor", in H. Westman, ed., Man and His Relationships, London, 1955,

pp.19,23-24, "Complementary Descriptions", p.391, and "Complementarity II", pp.116-117; and J.Baillie, The Sense of the Presence of God, London, 1962, pp.217ff.

49. "In order to characterize the relation between phenomena observed under different experimental conditions, one has introduced the term complementarity to emphasize that such phenomena exhaust all definable information about the atomic objects." APHK, p.99; cf. pp.40, 74,90, and Essays, pp.4,12,19,25,60,92.

50. "...the one or the other of two aspects of the description of physical phenomena, - the combination of which characterizes the method of classical physics, and which therefore in this sense may be considered as complementary to one another..." "Can Quantum-Mechanical Description, etc.", p.699.

51. ATDN, pp.19,56, and "Newton's Principles, etc.", p.60.

52. See ch.1.4 above.

53. "Indeed, however contrasting such experiences might appear when attempting to picture a course of atomic processes on classical lines, they have to be considered as complementary in the sense that they represent equally essential knowledge about atomic systems and together exhaust this knowledge." APHK, p.74; cf. p.26, "Causality and Complementarity", p.291, and "On the Notions of Causality and Complementarity", p.314.

54. "Physical Science and the Study of Religions", p.387, APHK, p.5.

55. "Chemistry and the Quantum Theory, etc.", p.376.

56. ATDN, p.10.

57. "Although the phenomena in quantum physics can no longer be combined in the customary manner, they can be said to be complementary in the sense that only together do they exhaust the evidence regarding the objects, which is unambiguously definable." "Newton's Principles, etc.", p.60; cf. ATDN, p.56, and APHK, p.40.

58. e.g. "...the essential non-analyzability of atomic stability in mechanical terms presents a close analogy to the impossibility of a physical and chemical explanation of the peculiar functions characteristic of life." APHK, p.9; cf. p.6.

59. "...the concept of stationary states may indeed be said to possess, within its field of application, just as much, or, if one prefers, just as little 'reality' as the elementary particles themselves." ATDN, p.12; cf. p. 87.

60. e.g. N.R.Hanson, The Concept of the Positron, pp.2-3; A.Landé, Principles of Quantum Mechanics, Cambridge, 1937, pp.x, 8-9, Quantum Mechanics, London, 1951, pp. 22,298; and W.H.McCrea, "Action at a Distance", Philosophy 27, 1952, pp.75-76.

61. "The Quantum Postulate, etc.", p.581 = ATDN, pp.57-59; see L.de Broglie, "Recherches sur la Théorie des Quanta", Annales de Physique 3, 1925, pp.22-128.

62. ibid.

63. E.Schrödinger, "Über das Verhältnis der Heisenberg-Born-Jordanschen Quantenmechanik zu der meinen", Ann.Phys. 79, 1926, pp.734-756; cf. fn.15 above; N.R.Hanson, "Are Wave Mechanics and Matrix Mechanics Equivalent Theories?", in H.Feigl and G.Maxwell, eds., op.cit., pp.401-425; and P.A.M.Dirac, "Foundations of Quantum Mechanics", Nature 203, 1964, pp.115-116.

64. M.Born, "Quantenmechanik der Stossvorgänge", Zeit.Phys. 38, 1926, p.805.

65. The latter two kinds of particles are still largely hypothetical. For a good semi-popular presentation, see V.Guillemin, The Story of Quantum Mechanics, New York, 1968, ch.12. For a mathematical treatment, see e.g. D. Lurié, Particles and Fields, New York, 1968. Note that when acceleration occurs fields become waves and virtual particles become real particles.

66. Unfortunately, Bohr never fully developed his thoughts on the role of complementarity in quantum field theory; but see N.Bohr and L.Rosenfeld, "Field and Charge Measurements in Quantum Electrodynamics", Phys.Rev. 78, 1950, esp. pp.794,798.

67. e.g. M.Born, "Bemerkungen zur statistischen Deutung der Quantenmechanik", in F.Bopp, ed., op.cit., p.113; and A.Landé, "Dualismus, Wissenschaft und Hypothese", ibid, pp.122-123.

68. cf. Reichenbach's "principle of anomaly"; e.g. Philosophic Foundations of Quantum Mechanics, Berkeley, 1944, p.33; see below, ch.4.9.

69. "The Quantum Postulate, etc.", p.581. The difference between the propagation and collapse of a wave corresponds to von Neumann's distinction between automatic, continuous, reversible, causal changes of a "pure state" and arbitrary, discontinuous, irreversible, statistical changes to a "mixture" (J.von Neumann, op.cit., pp.351, 357-358; cf. E.P.Wigner, op.cit., p.155). However, for von Neumann (and Wigner) the "wave-function" is merely the statistical description of an ensemble of identical systems and its collapse does not occur until the results of a measurement enter human consciousness, whereas

for Bohr the "wave-mode" is a physical system in itself which collapses whenever its macroscopic environment requires it (see J.von Neumann, op.cit., pp.298, fn.156, and 418-420; and E.P.Wigner, op.cit., pp.172,176). On the difference between Bohr and von Neumann see A. Shimony, "The Role of the Observer in Quantum Theory", Am.J. Phys. 31, 1963, pp.758-768; L.Rosenfeld, "The Measuring Process in Quantum Mechanics", Prog.Th.Phys., Supplement, Extra No., 1965, p.223, "Questions of Method in the Consistency Problem of Quantum Mechanics", Nuc.Phys. A108, 1968, pp.241-242; D.L.Schumacher, "Time and Physical Language", in T.Gold and D.L.Schumacher, eds., The Nature of Time, Ithaca, 1967, pp.196-213; T.Bastin, ed., op. cit., pp.4,65,71,86,95, and C.A.Hooker, loc.cit., pp. 158-159.

70. "The Quantum Postulate, etc.", p.585.

71. "Maxwell and Modern Theoretical Physics", p.692, "Field and Charge Measurements, etc.", p.794; cf. C.F.von Weizsäcker, "Komplementarität und Logik", p.523; and L.de Broglie, New Perspectives in Physics, Edinburgh, 1962, pp.9-11.

72. e.g. APHK, pp.42-43.

73. If a shutter is used to define the instant of passage through the slit the wave will start out as a narrow wave-packet with poorly defined wavelength and frequency, but it will rapidly spread out in space, and as the uncertainty in position and time increases the uncertainty in momentum and energy (hence in wavelength and frequency) will decrease; cf. E.P.Wigner, op.cit., p.156.

74. de Broglie has even drawn a parallel with Zeno's paradox; an arrow cannot be in motion at the same time that it is located at a particular point: Matter and Light, London, 1939, p.254; see also A.Landé, "Causality and Dualism on Trial", in M.Bunge, ed., The Delaware Seminar in the Foundations of Physics, Berlin, 1967, p.339.

75. "The Quantum Postulate, etc.", p.586 = ATDN, pp.75-76, "On the Notions of Causality and Complementarity", p. 314. This is similar to James's analysis of the stream of consciousness into "an alternation of flights and perchings" or of "transitive parts" and "substantive parts" (Principles of Psychology, pp.243-244) as pointed out by M.Jammer, (The Conceptual Development of Quantum Mechanics, p.178).

76. APHK, p.43.

77. "It is a purely formal matter to say that these waves consist of photons since the conditions under which we control the emission and reception of the radio waves preclude the possibility of determining the number of photons they should contain. In such a case we may say

that all trace of the photon idea, which is essentially one of enumeration of elementary processes, has completely disappeared." "Maxwell and Modern Theoretical Physics", p.692.

78. In terms of the theory of spectral decomposition the collapse represents the selection of one actual particle position (Dirac delta-function) out of an infinite set of possible particle positions; see above, fn.64.

79. APHK, p.42; cf. "Can Quantum-Mechanical Description, etc.", p.697.

80. In terms of the theory of spectral decomposition the expansion of the spherical wave with well-defined frequency and wavelength represents the selection of one actual wave out of an infinite set of possible waves. The selection in this case is governed by the conservation laws for energy and momentum, hence the frequency and wavelength of the spherical wave will be the same as those of the plane wave before it; cf. fn.78 above.

81. APHK, p.43.

82. See above, p.21.

83. APHK, p.43.

84. "Free particles" here are particles with well-defined position and poorly defined momentum. They are produced during transitions between stationary states (corresponding to waves or "bound particles") either by emission or absorption or ionization.

85. See ch.1.5 above. The notion of 'potentiality' is introduced here as an aid to interpreting Bohr's statements about photons and electrons and to working out the implications of the logic of complementarity. Bohr never uses the term 'potentiality' himself, but I am arguing that the concept is implicit in his writings. In order to avoid misunderstanding, therefore, the concept must be viewed in the context of the passages I have cited and in relation to the logic of complementarity as a whole. It should not be identified with the Aristotelian notion of 'potency', for instance, although Aristotle does seem to take account of environmental conditions in his own definition (Metaphysics, Book Theta, ch.5).

86. "...the study of complementary phenomena demands mutually exclusive experimental arrangements." APHK, p.41; cf. pp.5,19,47,90, and Essays, pp.5,12,60.

87. "...a new mode of description designated as complementary in the sense that any given application of the classical concepts precludes the simultaneous use of other classical concepts..." ATDN, p.10; cf. p.19, and Essays, pp.5,61.

88. APHK, pp.73,90, and Essays, p.63.

89. "...the impossibility of combining phenomena observed under different experimental arrangements into a single classical picture implies that such apparently contradictory phenomena must be regarded as complementary..." Essays, p.25.

90. "Consequently, evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary..." APHK, p.40; cf. pp.7,26, and Essays, pp.4,12,92.

91. APHK, pp.30,40.

92. "Newton's Principles, etc.", p.60, APHK, p.40.

93. "Causality and Complementarity", p.293.

94. ATDN, p.107, "Causality and Complementarity", p.294, and APHK, p.40.

95. "The Quantum Postulate, etc.", p.580 = ATDN, pp.54-55, "Chemistry and the Quantum Theory, etc.", p.376, and "Physical Science and the Study of Religions", p.387.

96. "The Quantum Postulate, etc.", pp.587,589 = ATDN, pp.77-78,85; cf. p.35.

97. APHK, pp.5,19. N.Brody and P.Oppenheim call this "non-compatibility" rather than incompatibility: "Application of Bohr's Principle of Complementarity to the Mind-Body Problem", J.Phil. 66, 1969, p.98.

98. e.g. ATDN, pp.71,73,76,95. As Meyer-Abich points out (op.cit., p.152), Bohr never called conjugate properties themselves complementary. Only the modes in which they are respectively defined are complementary (contra P. Bernays, "Über die Ausdehnung des Begriffes der Komplementarität auf die Philosophie", Synthese 7, 1948, p.66). The term "conjugate" comes from the canonical Hamiltonian formulation of classical mechanics in terms of generalized position and momentum coordinates. The product of two conjugate quantities (like position and momentum) always has the units of angular momentum or "action" (hence the "quantum of action").

99. ATDN, p.11.

100. ATDN, pp.68,98,114, and APHK, pp.40,72.

101. M.Born and P.Jordan, "Zur Quantenmechanik", Zeit.Phys. 34, 1925, p.871; and M.Born, W.Heisenberg, and P.Jordan, "Zur Quantenmechanik II", Zeit.Phys. 35, 1926, pp.562, 577; cf. N.Bohr, "The Quantum Postulate, etc.", p.585 = ATDN, p.71, and Essays, pp.5,61.

102. W.Heisenberg, Über den anschaulichen Inhalt der quanten-theoretischen Kinematik und Mechanik", Zeit.Phys. 43, 1927, p.175; cf. N.Bohr, "The Quantum Postulate, etc.", pp.581,582,583,585 = ATDN, pp.57,60,63,72-73, APHK, p.72, and Essays, p.5. On the problem of interpreting the role of time in the uncertainty relations see D.Bohm and Y.Aharanov, "Time in the Quantum Theory and the Uncertainty Relation for Time and Energy", Phys.Rev. 122, 1961, pp.1649-1658.

103. e.g. ATDN, p.95. It is variously cited as h, h/2, $h/2\pi$ and $h/4\pi$.

104. ATDN, pp.18-19,94-95.

105. e.g. ATDN, p.60, APHK, p.72, and Essays, p.5.

106. e.g. ATDN, p.87.

107. $h = 6.55 \times 10^{-27}$ erg seconds.

108. On the reinstatement of real becoming in modern physics seeM.Čapek, The Philosophical Impact of Contemporary Physics, Princeton, 1961, ch.17.

109. M.Born, "Quantenmechanik der Stossvorgänge", p.804; cf. N.Bohr, "The Quantum Postulate, etc.", p.586 = ATDN, pp.74-75.

110. APHK, p.34, and Essays, p.4.

111. ATDN, p.12, APHK, pp.5,71,90, and Essays, pp.11-12,25, 60,92.

112. See ch.1, fn.82.

113. See ch.1.5, esp. fn.122.

114. Hence this "irreversibility" is itself statistical; cf. D.Bohm, Quantum Theory, pp.415, 608f; and Y.Aharonov et al., "Time Symmetry in the Quantum Mechanical Process of Measurement", Phys.Rev. 134, 1964, pp.B1410-B1416. On the perennial problem of time reversal see D.Williams, "The Myth of Passage", J.Phil. 48, 1951, pp.457-472; H.Reichenbach, The Direction of Time, Berkeley, 1956; M.Čapek, op.cit., chs.11ff; H.Mehlberg, "Physical Laws and Time's Arrow", in H.Feigl and G. Maxwell, eds., op.cit., pp.105-138; R.Schlegel, Time and the Physical World, East Lansing, 1961; G.J.Whitrow, The Natural Philosophy of Time, London, 1961, ch.6, and What Is Time?, London, 1972, ch.7; A.Grünbaum, "The Nature of Time", in R.G.Colodny, ed., Frontiers of Science and Philosophy, pp.147-188, and Philosophical Problems of Space and Time, London, 1964; J.J.C.Smart, Philosophy and Scientific Realism, London, 1963, ch.7, and Problems of Space and Time, New York, 1964; O.Costa

de Beauregard, "Irreversibility Problems", in Y.Bar-Hillel, ed., op.cit., pp.313-342; R.Fischer, ed., Interdisciplinary Perspectives of Time (Annals of the New York Academy of Sciences, 138, 1967, pp.367-915), Part 1; T.Gold and D.L.Schumacher, eds., The Nature of Time, Ithaca, 1967; J.T.Fraser, ed., The Voices of Time, London, 1968, part 4; R.Swinburne, Space and Time, London, 1968, R.M.Gale, The Language of Time and The Philosophy of Time, London, 1968; J.Zeman, ed., Time in Science and Philosophy, Prague, 1971, Part 1; J.T.Fraser et al., eds., The Study of Time, New York, 1972, Part 1; B.Gal-Or, "The Crisis About the Origin of Irreversibility and Time", Science 176, 1972, pp.11-17; and R.G.Sachs, "Time Reversal", Science 176, 1972, pp.587-597.

115. APHK, pp.89,98, and Essays, pp.3,24-25,61,92.

116. "In the language of the relativity theory...a general reciprocal relation exists between the maximum sharpness of definition of the space-time and energy-momentum vectors associated with the individuals. This circumstance may be regarded as a simple symbolical expression for the complementary nature of the space-time description and the claims of causality." "The Quantum Postulate, etc.", p.582 = ATDN, p.60.

117. The probability of collapse to any point is proportional to the density of the "blur" at that point.

118. Bohm has stressed the fact that the shape of the cell in phase space is determined by experimental conditions: "On Bohr's Views Concerning the Quantum Theory", pp.36-38.

119. Perhaps this is the best point at which to discuss the difference between the complementarity of modes and Karl Heim's 'contact of spaces' (God Transcendent, London, 1935, pp.70ff). Heim is concerned with the point of intersection between two perpendicular lines or dimensions (in fact, there is no real 'contact' since the lines have no width) like those shown in the sketches above. The point of intersection obviously satisfies the condition of unity, and the two lines which define it are equally important and mutually exclusive, as well. But they do not satisfy the condition of individual completeness for, in spite of the fact that the point belongs "wholly and completely" to both lines (op.cit., p.70), it can only be described in terms of their intersection and not in terms of either of the lines individually. In fact, the point of intersection does not share any of the characteristic properties of the two lines since only an infinitessimal portion of either line is present in the point; in other words, they are not 'fully present'. Moreover, the two lines are not coexhaustive since more dimensions can be added indefinitely, and there is no coinherence or alternation between them. Either of the sketches above would

describe the point of intersection for all time since Heim's idea is static and lifeless. Finally, the 'contact of spaces' is entirely symmetrical with respect to its two dimensions and hence will not satisfy the two conditions that we are about to discuss, emergence and pointing.

120. "...the complementary relationship between the stability properties of the atoms themselves and such behaviour of their constituent particles as allows of a description in terms of space-time coordination." APHK, p.21; cf. pp.6,9,19,21, ATDN, pp.23,81, and Essays, pp.2,11,63.

121. "Here, the complementary description offers indeed the adequate approach to the problem of atomic stability with which we were faced from the very beginning. Thus, the interpretation of spectral regularities and chemical bonds refers to experimental conditions mutually exclusive of those which permit exact control of the position and displacement of the individual electrons in the atomic systems." Essays, p.63; cf. above, ch.1, fn.158.

122. "Causality and Complementarity", p.296, and APHK, pp.7, 99.

123. "...just this complementary mode of description leaves room for regularities in atomic processes foreign to mechanics but as essential for our account of the behaviour of living organisms as for the explanation of the specific properties of inorganic matter." APHK, p.7; cf. Essays, p.5.

124. APHK, p.99, and Essays, pp.25,63.

125. "Chemistry and the Quantum Theory, etc.", p.373, APHK, p.99, and Essays, pp.25-63.

126. "Chemistry and the Quantum Theory, etc.", p.369, APHK, p.99, and Essays, p.2.

127. "Chemistry and the Quantum Theory, etc.", pp.349,376; cf. fn.19 above.

128. Contrast Polanyi's "complementarity" of analysis and integration: Knowing and Being, p.125.

129. ATDN, pp.23,35,54-55,77-78, APHK, pp.6-7,19,21,99, and Essays, pp.5,11,25,63.

130. See p.23 above.

131. Essays, p.5; cf. the application of the concept of stationary states (ATDN, pp.23,77-78, APHK, pp.6-7) and the non-analyzability of atomic stability in mechanical terms (APHK, p.9).

132. "The Quantum Postulate, etc.", p.582 = ATDN, pp.62-63. For the parallel treatment of energy measurement, see ibid, pp.587-588 = ATDN, pp.80-81.

133. See ch.1, fn.169. Note that the "pointing relation" described here is perpendicular to Polanyi's "from-at" relation.

Chapter 3

Bohr's Use of Complementarity in Other Fields

> "Around these ideas the philosophical and theological battle has raged for centuries because men have always set their hearts on bringing everything into one system. Now the impossibility of this has become apparent even in physics, that most rigorous and simple of sciences; even here the complementary attitude to differing aspects is necessary. Hence we must expect this everywhere." M.Born, Physics and Politics, p.57.

From the very start Bohr drew analogies between the principle of complementarity in atomic physics and older, more familiar relationships in biology and psychology.[1] He did this for a twofold purpose: to help explain the novel developments in physics and, conversely, to provide a basis for reinvestigating the more familiar problems in other fields.[2] For Bohr these analogies were not merely heuristic guides, however, for behind them lay a logical kinship due to the universality of the basic principles of epistemology and ontology.[3]

3.1 Statistical Thermodynamics - Microstate and Macrostate:

Statistical thermodynamics is a complex subject, and, unfortunately, Bohr has not given us a thorough treatment.[4] From the viewpoint of complementarity the essential features are these: a large system of identical atoms or molecules exists in one of two modes, either as a mechanical system with a well-defined microstate (the positions and momenta of all the molecules are determined)[5] or as a thermodynamic system with a well-defined macrostate (the temperature and entropy of the system as a whole is determined)[6]. One of the most striking paradoxes of classical physics is the fact that the basic laws of mechanics (Newton's laws) are strictly reversible whereas irreversibility is an essential feature of thermodynamics (the second law of thermodynamics - entropy increases monotonically in isolated systems)[7]. Bohr regarded this paradox as a clear example of complementarity between laws of nature which require mutually exclusive experimental conditions. On one hand, there is the complete control or detailed description of the motions of individual molecules; on the other hand, there is the definition and application of the concepts of temperature and entropy.[8] All of this holds true in classical physics itself and is completely independent of the existence of complementarity in quantum mechanics.

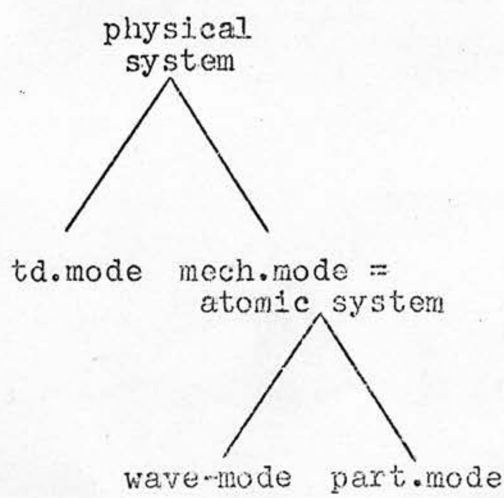
Now the temperature of a thermodynamic system can be defined in one of three ways:[9] (1) In the Maxwell-Boltzmann treatment of kinetic theory temperature is defined as a parameter determining the breadth of the velocity distribution of molecules based on the assumption of "molecular chaos" (complete randomness in the motions of the individual molecules)[10]. This can be interpreted in one of two ways; either that the temperature itself is a measure of uncertainty in the individual velocities of the molecules or that the very definition of the temperature presupposes this uncertainty.[11] (2) In the more general Boltzmann treatment of statistical mechanics, temperature is defined as a measure of the breadth of the energy (and hence velocity) distribution of the molecules based on the assumption of equal a priori probability (hence equal uncertainty) of all the available microstates (Liouville's theorem).[12] (3) In the Gibbs treatment of statistical mechanics, temperature is defined by means of a "canonical ensemble" of identical systems in thermal equilibrium with a heat reservoir. While their temperature is determined their energies fluctuate about a mean value, and hence their microstates are uncertain. Conversely, the definition of energy requires a "microcanonical ensemble" in which the systems are all isolated and their temperatures are uncertain.[13] Since this approach is inherently statistical, treating large ensembles of identical systems rather than individual systems,[14] it is less convincing than the Maxwell-Boltzmann approach which treats individual systems. Bohr utilized it, however, because it brings out the complementarity relationship so clearly.[15]

A comparison of this use of complementarity with the eleven points of complementarity in atomic physics shows almost complete agreement.[16] The only questionable point of comparison is the condition of evolution by alternation between the two modes. It is not generally recognized that a thermodynamic system evolves by alternation between the definition of microstate and macrostate in response to environmental changes because the environment is usually assumed to be constant. Hence,a thoroughly complementarist treatment will require an analysis of the non-equilibrium thermodynamics of interacting systems.[17]

Two further points should be emphasized to distinguish Bohr's treatment from the alternative notion of "orthogonality". The mechanical and thermodynamic modes are mutually exclusive in reality since they require mutually exclusive conditions for their definition, and under a given set of conditions the system is completely understood in terms of the appropriate mode of existence (conditions 3 and 8). The more usual view of thermodynamics is represented by Polanyi, who likens the emergence of randomness in thermodynamic systems to the "emergence" of randomness in a shuffled pack of cards.[18] In both cases, according to Polanyi, the emergence depends on our not knowing the detailed ordering of the system, an ordering which nonetheless exists. Since it depends on individual knowledge, the emergent quality may exist for one observer, who is ignorant of the details, but not for another, who has discovered them. In fact, the second law of thermodynamics will hold for the one observer, but not for the other.[19] In other words, for Polanyi, the two modes represent two ways of looking at the same reality, two orthogonal dimensions of the object itself which exclude each other in thought and experience, but not in reality. Hence, the modes coexist in reality, and neither one of them fully accounts for the object as it exists in any given circumstance. Here the contrast between orthogonality and complementarity carries over from atomic physics into thermodynamics.

Even though Bohr said relatively little about the role of complementarity in thermodynamics, the importance of this application cannot be overstressed. Statistical thermodynamics is the only field of application outside atomic physics which has been rigorously formulated, or indeed is capable of being completely formalized mathematically. Therefore, the existence of complementarity in thermodynamics gives strong support to Bohr's contention that the parallels he draws between different fields are not just "vague analogies", but "clear examples of logical relations which, in different contexts, are met with in wider fields."[20]

Furthermore, the examples of complementarity in atomic physics and thermodynamics are not only <u>logically parallel</u>; they are also <u>hierarchically related</u> (though physically independent). The mechanical mode of a physical system consists of individual atoms or molecules, but these atoms or molecules, in turn, exist in one of two modes, either as waves (stable atoms) or as groups of elementary particles. In other words, the microstate of a classical system of molecules consists of specifying the positions and momenta of all the individual molecules, but quantum-mechanically these can be defined only under mutually exclusive conditions. In fact, a very precise definition of the positions is incompatible with the stability of the molecules themselves. Consequently, the complementarity of atomic systems can be treated as a subdivision of the complementarity of systems of atoms, or physical systems in general. This subdivision is best represented visually by a "tree diagram".



Here we have a hierarchical structure with three levels: that of stable physical systems (of many atoms), that of stable atoms, and that of elementary particles.[21] The tree-diagram is misleading in some respects, however. It makes the relationships appear static like those of a grammatical hierarchy whereas the modes in complementarity are continually in alternation. It also makes the higher levels appear to be invariant as if they could exist amodally themselves. To counteract these tendencies, one must always remember to work his way downwards as far as possible along a given branch of the tree and to repeat this process whenever the object switches from one mode (represented by a branch) to another. For instance, if a physical system is in the thermodynamic mode no further specification is necessary. But, if it switches to the mechanical mode, then one must further specify whether it is in the wave or particle branch. Under these conditions, the tree-diagram will be an extremely useful tool in our mapping of the logic of complementarity.

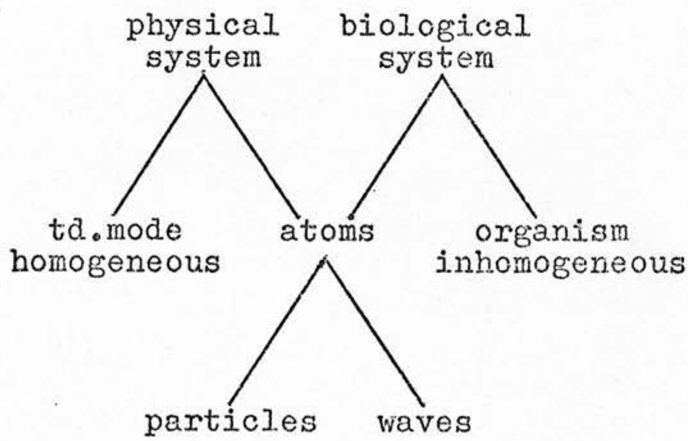
3.2 Biology - Atom and Organism:

Bohr treated the application of complementarity to biological science more thoroughly than any other, thus reflecting the deep interest in the problem of mechanism and vitalism instilled in him by his father.[22] His basic thought is that a biological entity may exist in one of two modes, either as <u>a system of atoms and molecules</u> governed by the laws of physics and chemistry or as <u>an organism</u> governed by peculiar laws of its own.[23] Which mode is actualized depends, of course, on the experimental conditions, i.e. whether the entity is experimentally analyzed as a physico-chemical system, in which case no life can exist,[24] or whether the integrity of the organism is respected and indwelt as part of "that nature to which we belong" ourselves.[25] It follows that there is no violation of the laws of physics and chemistry in life processes, on one hand; they fully account for those situations in which they are well-defined (individual completeness).[26] But, on the other hand, life processes cannot be reduced to physico-chemical terms (equal importance).[27] Hence, the mechanistic and vitalistic viewpoints are not contradictory, but complementary, to each other.[28] The characteristic features that emerge in the organismic mode include individual uniqueness,[29] organization,[30] freedom,[31] rhythm,[32] wholeness,[33] self-stabilization,[34] self-preservation and regeneration,[35] irreversibility and memory,[36] purpose[37] and function,[38] and phylogenetic evolution.[39] But the fundamental, irreducible feature, analogous to the quantum of action in atomic physics, is <u>the fact of life itself</u>.[40]

Bohr's argument for the irreducibility of life processes is based on an analysis of the possibilities of both observation and definition.[41] Clearly, the individual atomic processes can not be observed without destroying the organismic features, but neither can they be suitably defined in a living being. Bohr argued the latter point in two ways: (1) In his earlier writings he based his reasoning on the necessity of a sharp boundary between the biological object and its environment for unambiguous communication.[42]

On the ecological level this distinction is possible, but on the atomic scale it is not possible since life processes involve a continual exchange of atomic matter with the environment. Therefore, the very definition of life is incompatible with the unambiguous definition of individual atomic processes.[43] (2) In his later writings Bohr stressed the <u>fundamental complexity</u> of biological organisms due to the huge number of atoms involved in the maintainance of life processes[44] and, in contrast to machines or crystals, the <u>extreme inhomogeneity</u> or <u>irregularity of structure</u> on the atomic scale.[45] Together these conditions imply the utter impossibility of defining the atomic state of an organism, even by statistical methods, while life processes are going on.[46] The two arguments Bohr used are closely related since the continual exchange of matter is one aspect of the complexity and irregularity of living organisms on the atomic scale.

Certainly these arguments are much more intuitive and fallible than the more rigorous reasoning for complementarity in atomic physics and thermodynamics. In fact, it may never be possible to formalize biological science to the point where they can be decisively evaluated. Complementarity may always have to be regarded as an hypothesis in biology, accepted by some and repudiated by others (as indeed it still is in atomic physics). Nonetheless, complementarity is to be expected in biology, even though it cannot be rigorously demonstrated, because of the <u>parallel to thermodynamics</u>, where it can. Just as complementarity in thermodynamics is related hierarchically to complementarity in atomic physics, so it is (plausibly) with biology and physics. In fact, biology and thermodynamics represent *two possible directions of emergence* above the atomic level, one of *radical inhomogeneity* and the other of *relative homogeneity*. The emergenge itself, then, is a matter of complementarity, but the direction of emergence is a matter of the degree of homogeneity. Just as one group of atoms or molecules may belong to a thermodynamic system, so another, less homogenous group may belong to a biological organism.



Therefore, Bohr's heuristic arguments for complementarity in biology are supported by a fundamental belief in *the common structure of the sciences*, reflecting a common structure of the various levels of reality which they study.

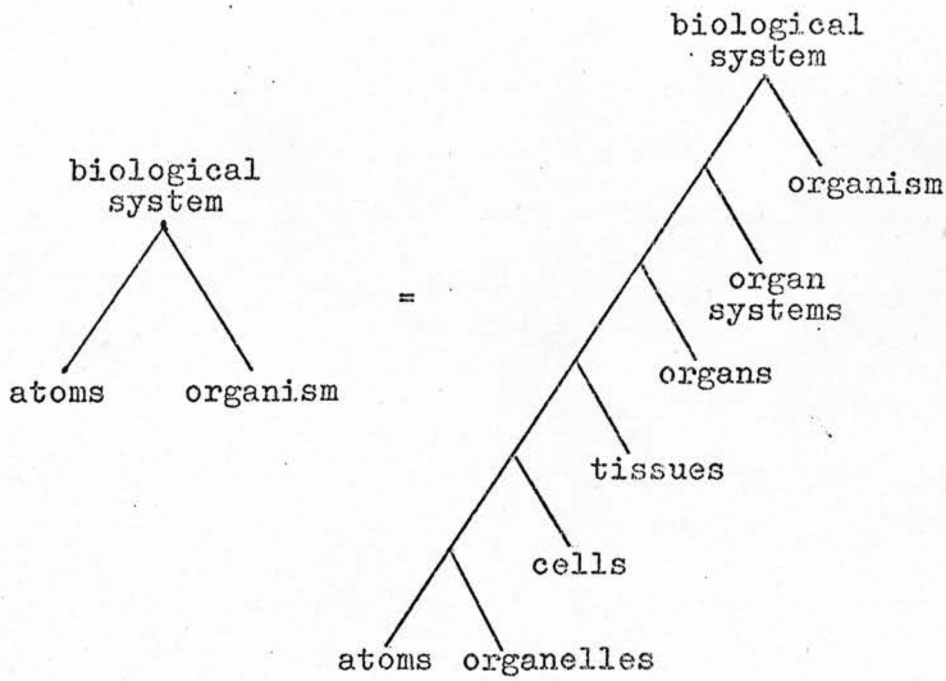
In reality, of course, the situation in biology is usually much more complex than that in thermodynamics. A highly-evolved organism is not simply composed of atoms and molecules like a thermodynamic system. There are also intermediate levels of organization like those of organelles, cells, tissues, organs and organ systems.[47] In fact, at each of these levels there is a relation of complementarity between the structure of the unit at that level and the function the same unit fulfils at the next higher level.[48] Such a function-structure unit is called a "tagmeme" in linguistics.[49] Originally designed for use in grammatical analysis, "tagmemics" can be applied to a variety of fields [50] and is ideally suited for the complementarist approach to biology. Suppose an organism is composed of several organ systems: a circulatory system, a digestive system, a respiratory system, a nervous system, etc. Each of these terms designates a function within the organism as a whole, but they are ambiguous in that they couple structural ideas together with functional ones. In tagmemics (or complementarity) we must clearly distinguish function from structure, hence we shall restrict these terms to their functional sense and use the terms heart-system, stomach-system, lung-system, and brain-system to designate the structural counterparts. Then a tagmemic formula for the organism in question would read:[51]

Organism = + circulatory system: heart-system
+ digestive system: stomach-system
+ respiratory system: lung-system
+ nervous system: brain-system + etc.

Then each of these structural units would have to be further analyzed at the organ level. Again the units are function-structure composites or tagmemes. For example, the formula for the heart system would read:

heart-system = + pumping mechanism: heart
+ distribution system: arteries
+ collection system: veins
+ connecting system: capillary system

Each of these organs would then have to be analyzed at the tissue level and so on. The difference between an organism and a grammatical structure, however, is that the levels of an organism do not coexist (from the complementarist viewpoint) but continually alternate as the organism evolves (ontogenetically).[52] Using the tree-diagram again, we may represent the alternative levels of branches as follows:



For simplicity, we shall use the abbreviated form on the left since we shall be more concerned with the relation of biology as a whole to other sciences rather than with the detailed structure of biology itself.[53]

3.3 Psychology - Body and Mind:

After biology and physics, psychology was Bohr's favourite field of application for the principle of complementarity.[54] There are two distinct approaches to this subject in Bohr's writings: one is "subjective", based on the problems of introspection, and the other is "objective", based on the problems of applying the laws of physics and physiology to the study of psychic phenomena.

In any unambiguous reference to our own conscious states, says Bohr, we must make a clear distinction between the content of consciousness, upon which we are focusing our attention, and the background which we call "ourselves".[55] The immense richness of mental life is due to the variety of possible locations for this subject-object boundary and the continual shifting back and forth.[56] Normal healthy people instinctively adapt to these alterations and so hardly notice them, but there are psychiatric cases of "confusion of the egos" or "split-personality" in people who fail to make the necessary adjustments.[57] Alternatively, Bohr argues that a sharp distinction between psychic phenomena and their conscious perception is never possible[58] since any act of introspection shifts the subject-object boundary inwards and automatically alters the content of consciousness.[59] Either way, an emotion felt and an emotion analyzed are two different things, not to be confused.[60] The same is true of a decision made and a decision analyzed. The analysis of one's motives can never provide an argument against free volition because the two phenomena are complementary and therefore never in direct conflict.[61] In the same manner, Bohr frequently spoke of complementarity between seriousness and humor,[62] thoughts and feelings,[63] reason and instinct,[64] and knowledge and belief.[65]

For comparison, Bohr's shifting-boundary model of consciousness can be related to the internal stimulus-response cycle of Dollard and Miller or to the inner speech model of Vygotsky. Bohr would say that mental life proceeds by a continual shifting of the subject-object boundary so that at one moment a thought or feeling or perception is indwelt (subject) and at the next moment it is analyzed (object). If we view this process from the rest frame of the subject-object boundary itself, then it will appear that the thought moves back and forth across the boundary line as it changes from one mode to the other. In Polanyi's idiom, it is alternatively "interiorized" (in our subsidiary awareness) and "alienated" or "exteriorized" (into our focal awareness).[66]

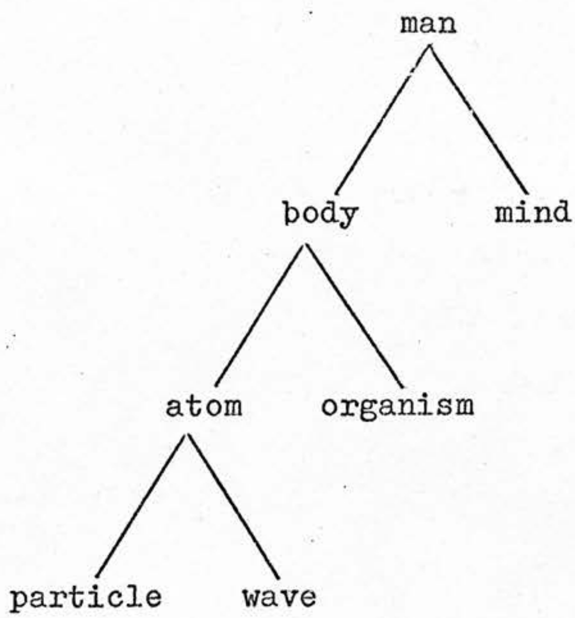
Bohr model			cyclical model
S-O boundary thought indwelt	————————		thought analyzed
	thought	S-O boundary	————————
S-O boundary thought analyzed	———————— background		thought indwelt
Bohr model thought stationary S-O boundary moves			cyclical model boundary stationary thought moves

Then the process of thinking is an internalized form of the familiar cycle of writing down an idea, looking at it, reflecting on it, thinking of the next step, and writing it down. It is a kind of "reflex circuit"[67], or "functional circle" (<u>Funktionskreis</u>),[68] or "stimulus-response" cycle[69] that has been internalized. There may be a large number of these internal responses, by which we visualize our next move and anticipate its consequences, before the final commitment to an outward response in the external world. The ability to carry on sustained thought in this way is, of course, characteristic of man and clearly distinguishes him from other animals.[70]

Moreover, this ability to think involves the use of language so its development in the individual must be related to the development of language behaviour. Years ago, Vygotsky suggested that the development of thought in a child takes place as the phenomenon of "egocentric-speech" is transformed into "inner speech".[71] Young children (three to seven years) often talk to themselves as they play, but as they grow older and learn to play with other children this "egocentric-speech", as it is called, gradually fades away. Piaget originally suggested that it simply vanishes as the child becomes more socialized,[72] but Vygotsky disagreed with this interpretation and tried to show that it is really internalized and gives rise to conscious thought. This notion is certainly plausible, at least intuitively, and it may help to clarify Bohr's more unusual presentation of the structure of consciousness.

What then is the relationship between the consciousness or mind and the body? Bohr suggested that the usual view of "psycho-physical parallelism" could be generalized and reinterpreted in terms of complementarity.[73] There can be no violation of causality in the physiological processes of the nervous system since the laws of physics and biology fully account for those phenomena in which they are well-defined. However, such a detailed analysis of another person's nervous system is clearly incompatible with his exercise of free will.[74] Therefore, the laws of physics and biology are not applicable to mental phenomena themselves, and <u>the fact of ffee will</u>, which we know intuitively, must be taken as an irreducible postulate in psychology just as the existence of life is in biology.[75] In fact, the only way to predict another pèrson's actions while respecting his freedom is to put oneself in his place.[76] This concept of "indwelling" is very close to Dilthey's concept of <u>Verstehen</u> or "empathy", except that it is not inconsistent with rationality or objectivity and it is not restricted to the "sciences of the spirit".[77] It can also be compared with Polanyi's concept of indwelling except that, for Polanyi, one knows another person's mind by indwelling his physiognomy and behaviour and attending away from these to his mind.[78] Hence the mind is specifiably known while the body (actually only its surface) is known tacitly. For Bohr, however, mind and body are the two modes of man's being: to indwell man <u>as man</u> is to know his mind (tacitly), and to analyze him <u>as an animal</u> is to know his body (specifiably).[79] Hence the relationship between mind and body is one of complementarity and not a "from-at" relation in Polanyi's sense.[80]

When we treat mind as complementary to body we automatically avoid the pitfalls of dualism (by the condition of unity) and epiphenomenalism (by the conditions of individual completeness and equal importance).[81] Man is a single being existing alternately in one of two modes, the mental and the physical, where the physical mode or body is further subject to modal existence as we have seen in the previous section.[82] A full representation of the alternative possibilities for man's existence would look something like this:



A man can be treated either as a group of particles (physically) or as a compound of atoms and molecules (chemically) or as a living organism (biologically) or as a conscious mind (psychologically), and all four of these views are correct in their respective circumstances.[83] None of them can be reduced to the others. Of course, the real situation is far more complex: the atom-organism unit is really an abbreviation for the more elaborate structure shown on page 97, and a more detailed investigation of the mind-body unit would undoubtedly reveal a series of intermediate levels there as well.[84] However, the basic structure is not affected by these refinements, and the underlying logic is most vividly portrayed by a simple model like this one.

At this stage we can better understand the nature of the use of tools with which we began our study of complementarity.[85] When not being used, a tool is simply a compound of atoms and molecules. In the case of a machine, it may be a thermodynamic (or some other kind of higher) system. But, when it is used by man in accordance with its proper function, it becomes _an extension of man's body_ and enters into complementarity with man's mind. In other words, _there exists a relationship of complementarity between every artifact and the idea which originally inspired its design and continues to inspire its proper use._[86] The ideas exist properly only in the mind of man so they may be distorted or even forgotten. We are surrounded by the lifeless artifacts of previous generations whose meaning or purpose has been lost in this way. Nonetheless, they bear silent testimony in the sense that they "point" to the ideas which gave them meaning and thus tantalize the research worker, so that the rebirth of those ideas always remains a potentiality within them (conditions of pointing and coinherence).[87] An obvious example would be the hieroglyphs of ancient Egypt which were unintelligible for over two thousand years until Francois Champollion deciphered them in the early nineteenth century. The science of archaeology also shows this complementarity: an archaeologist will ignore hundreds of chipped stones in his excavation, but he will put a few of these stones in a museum just because they show signs of human workmanship. _There is an "infinite qualitative difference" between two objects of similar size_

<u>and appearance simply because one is capable of evoking the idea which inspired its design</u>.

Man, then, is characterized by the ability to extend the limits of his own body through the use of tools. In fact, the subject-object boundary can be moved outwards to include a whole series of artifacts as in games of skill like billiards where three or four artifacts may be indwelt at a time (e.g. a combination shot in "eight ball" or snooker). Subhuman animals like chimpanzees can design and use simple tools under special conditions, but their ability to extend themselves in this way is severely limited.[88] Moreover, man is not limited to indwelling objects of his own making. Science, history and religion are all based on his ability to indwell and interpret objects and events in various ways. For instance, by constructing and indwelling appropriate models (systems of ideas) with his mind, man is able to extend his subjecthood into the natural world indefinitely. And in the religious experience of <u>ecstasy</u> the mystic attempts to indwell all of nature and extend his subjecthood to include the universe as a whole. If complementarity is valid here, this indwelling should point him beyond nature to God.[89]

Man is also capable of shifting the subject-object boundary indefinitely inwards. Just as one can treat an external object as a part of one's body by indwelling it, so one can treat a part of one's body as an external object by exteriorizing or alienating it. If I concentrate on my arm as an object, it becomes lifeless as if paralyzed. In order to move it I must reoccupy it as subject, but then it ceases to be an object for me.[90] This exteriorization or alienation is a common technique in forms of meditation like yoga. These methods involve a withdrawal from the world and a retraction of subjecthood in a movement of _enstasy_. In fact, the two basic forms of religious awareness, the enstatic and the ecstatic,[91] can be understood as the direct consequence of man's ability to shift the boundary between subject and object. Then the fundamental issue of salvation by works or by grace is determined by whether the boundary shift is controlled by man or by God or both.

We have seen that there is a close connection between the use of tools and the nature of mind. From the complementarist viewpoint, then, we may _define mind_ (the characteristic of man) as the _capacity for subjecthood_, i.e. the ability to extend the limits of one's body, to enter into complementarity with external objects (as with one's body) and fill or indwell the proximal side of the subject-object boundary; hence the ability to follow shifts in that boundary (whether or not these are under one's control) and to recognize the proper function of objects, the meaning of symbols, and even the presence of God. Furthermore, it is by the creation and "manipulation" (interiorization and exteriorization) of _ideas_ or _thoughts_ that man's mind exercises this capacity. In order to use a tool properly or interpret an event correctly and thus include it within his "body", man must discover the function or significance of the tool or event and indwell it with his mind. Hence, there are two dimensions of complementarity involved in the everyday behavior of man: a "_horizontal_" _complementarity_ between a tool-analyzed and the-same-tool-applied (on the bodily level) or an idea-analyzed and the-same-idea-applied (on the mental level - this is Bohr's "subjective" use of complementarity in psychology discussed above), and a "vertical" complementarity between each tool and the idea behind it parallel to that between body and mind (Bohr's "objective" use of complementarity in psychology). Hence Bohr's two uses of complementarity in psychology are intimately related, though quite distinct.

Here we cannot avoid the issue of the existence of a world of ideas comparable to the world of physical objects. Ideas exist only in the mind of man, but do they exist separately in many isolated minds or is there a single world of ideas common to all (or most) men?[92] In other words, are the minds of men isolated like their brains, or is there some higher unity in the realm of ideas, some kind of common mind?[93] A fully adequate answer to these questions (from the complementarist viewpoint) would require a more elaborate formulation of complementarity than I have attempted here,[94] but this much can be said at any rate: one would expect from the logic of complementarity that a higher degree of unity would be possible in the mind than in the body, just as a higher degree of unity is possible in an organism than in a group of atoms, or in the wave-mode than in the particle-mode (condition of emergence). However, while nothing can unify men like a belief or an idea, it is also true that nothing else can divide men so strongly. The potential for greater unity is there, but along with it is the potential for greater division.[95] This is also true at the biological level, though to a lesser degree: two dissimilar organisms can be united in a symbiotic relationship while another two will destroy each other anti-biotically. Even at the chemical level, atoms with reciprocal valences readily combine to form molecules (homopolar bonds or convalent bonds) while others are mutually inert (e.g. the "inert gases").

Some degree of "common mind" may be inferred from the existence of a common culture since men who indwell the same artifacts must be inspired, to a large extent, by the same ideas. Hence the integrating influence of language, art and religious symbols. Such common artifacts literally create and preserve a common mind by drawing out the subjecthood of individual men onto a common ground.[96] In fact, it may be questioned whether those individuals who refuse or fail to be drawn out in this way (solipsists or autistic children) can be said to possess any knowledge or mind in the proper sense.[97]

Before leaving the subject of psychology we should note the gradual shift that has taken place in the logic of complementarity from its original formulation in quantum theory through its applications to biology and psychology. For one thing, in atomic physics there is virtually no correlation between the states of alternating modes. A pure wave can give rise to a particle over a wide volume of space and a particle can give rise to a wave within a wide range of momenta (although the selection must satisfy the conservation laws).[98] Clearly this will not do for living organisms in their natural state;[99] if an animal interacts with its environment on the molecular level (e.g. through the senses of perception) and then converts to the organismic or even the mental level, there must be some degree of correlation or propriety between the states (the explicit properties) at each of these levels (a kind of translation) if the animal is to respond appropriately and survive.[100] This need is less critical for plants than for animals, but even for them there is a greater degree of correlation than in the case of atoms or molecules. Bohr attributed this correlation to amplification effects between the various levels of existence and noted the striking irreversibility of sense perception (i.e memory) in organisms as a parallel to the irreversibility of the measuring process in physics.[101]

Furthermore, a kind of mirroring or imaging of the whole enters into psychology while it is absent from physics and biology. "Mind" can be related both to the individual and also to the entire race of man (or at least large portions of it). Hence, the individual is a microcosm, reflecting or imaging in some sense the being or essence of man as a whole. On one hand, the individual does not exist except as a part of the whole, and, on the other, the whole is fully present within each individual.[102] This paradox is quite distinct from the general problem of particulars versus universals or of parts versus wholes since it only occurs for social relations and is not present in the case of particles in an atom or atoms in an organism. It is related to the problem of individuality - the electrons of an atom completely lose their individuality because they are identical to each other. The same is true of atoms of the same kind in an organism. However, an organism is utterly unique and cannot lose its individuality even when it enters into social relations. Instead it internalizes these relations in the forms of language, emotion, a self-image, etc. - all the characteristics of "mind".[103] Therefore, an individual person cannot be isolated or abstracted from social relations as an individual atom or even an animal can. A person embodies those relations and carries them around with him, as it were; they enter into his very being. Hence the ambiguity of the word "man" (cf. Hebrew _Adam_): it may refer to the individual or else to the entire race. The same cannot be said of "Helium atom" or even "German shepherd". Hence, in the transition from physics to biology there is an emergence of "correlation" or "propriety" between the states of the alternate modes, and in the transition from biology to psychology there is an emergence of this "mirroring" or "imaging" of the whole in each individual. It should be noted, therefore, that the logic of complementarity is not a rigid scheme that can be imposed _a priori_ on new areas of study. Rather it is a flexible tool that must be adapted at each level of application in accordance with the progressive changes in the levels themselves. _A knowledge of the individual levels and of their corresponding sciences must always be presupposed_.

To summarize: there are four basic ideas in the overall logic of complementarity: (1) the eleven-point _complementarity relationship_ between alternate modes, (2) the relationship of homology or structural parallelism[104] between the applications of complementarity in various fields, (3) the hierarchical relationship of these applications, and (4) the progressive adaption of the basic complementarity relationship from one end of the hierarchy to the other.[105]

3.4 Cultural Anthropology and Sociology - A Counterexample:

Bohr sometimes referred to different human cultures as being complementary.[106] He stressed the mutual exclusiveness of cultural traditions,[107] the difficulty in appreciating the traditions of one culture in terms of those of another,[108] and the difficulty of separating cultural phenomena from the process of ethnological observation.[109] Of course, the same things could be said about different religious or political traditions or even about different paradigms within science.[110]

However, Bohr stated repeatedly that the word "complementarity" was not being used here in the strict sense in which it is used in atomic physics or psychology.[111] In particular, he pointed out that cultures are not strictly exclusive because of their contact with one another and the frequent fusion to form a new culture.[112] Moreover, the difficulty of appreciating other traditions can often be overcome by dialogue based on the many common features which cultures share.[113] In other words, the relationship between cultures does not satisfy the important condition of mutual exclusiveness; nor, for that matter does it satisfy the conditions of alternation, coinherence, emergence or pointing. The real value of Bohr's occasional references to anthropology and sociology is as a counterexample to show that the idea of complementarity is not so ubiquitous that it is simply meaningless.[114]

3.5 Ethics and Religion - Justice and Charity:

Justice and charity were also judged to be complementary by Bohr, his principle argument being that the strict application of law leaves no room for the free display of love, and, conversely that the free exercise of compassion may conflict with the ideal of justice.[115] In religious mythology according to Bohr, this reciprocity is often portrayed by a struggle between deities personifying the two opposing ideals.[116] Apparently he regarded this analogy to complementarity as a major contribution to theological science, but very few theologians have followed him up on it.[117] From a biblical standpoint, of course, the dichotomy of love and justice is totally unacceptable.[118] The two ideals are united in the ideal father, whether human or divine. There can be no true justice without charity and no true love without justice so the two ideals are not exclusive in principle even though they may often be in practice.[119] Even in dualistic traditions with opposing deities, complementarity would not hold since love and justice would then be conflicting realities rather than complementary modes of a single reality. Granted that theology was not Bohr's strong point, it is still surprising that he should have slipped so badly.

Considerable light has been thrown on the subject by Jerome S.Bruner who reports a conversation he had with Bohr in 1943 or early 1944.[120] Bohr told him that he had first experienced the dichotomy of love and justice when he found himself unable to discipline one of his children who had done something very bad. As Bohr expressed it, "You cannot know somebody at the same time in the light of love and in the light of justice." Apparently this experience made a deep impression on Bohr and provided the Sitz im Leben for his later discussions of the complementarity between the love and justice of God. Still it is surprising that Bohr should have extrapolated his personal experience so far particularly in view of his own words of caution to Einstein about ascribing attributes to Providence in everyday language.[121]

According to John Baillie, who attended the Gifford Lectures, Bohr also hinted at the possibilities of complementarity between human freedom and divine grace and between physical causation and divine providence.[122] Here we are dealing with two aspects of the doctrine of creation, the integrity of the creature and the sovereignty of God. We shall examine the logic of this relationship in chapter eight, but here we can at least note that a relationship of complementarity between man (representing creation) and God would provide a plausible extension of the hierarchy of complementarities discussed so far.

Finally, von Weizsäcker reports that Bohr referred in conversation to a complementarity between the immanence and transcendence of God with respect to time both in Eastern religions and in the Old Testament ("for You a thousand years are but a day": Ps.90.4, 2 Pet.3.8).[123] It is unfortunate that Bohr never developed this idea in print because it turns out to represent a critical stage in the progressive adaption of the logic of complementarity as we shall see in chapter eight. The idea of an alternation of modes in complementarity presupposes some kind of temporal framework and hence must be adapted to the limit if it is to be translated from time itself to eternity. On the other hand, God must not be thought of in static terms even in his transcendence, so the concept of eternity must allow dynamic features like "generation", "procession", and alternation.[124]

Several conclusions can be drawn from this survey of Bohr's applications of complementarity outside the field of atomic physics. First, Bohr saw complementarity as a quite <u>general principle</u>, not limited to any one field but <u>basic to the structure of all knowledge and all reality</u>, though in varying contexts.[125] Secondly, Bohr saw complementarity as an inherently <u>hierarchical structure</u>. The emergence of novel features in the tacit mode of one complementarity relation (e.g. free particles -stable atoms) allows that relation to nest within another parallel relation at a higher level (atoms - organism). Though this hierarchical structure was never explicitly worked out by Bohr, it can be inferred directly from his writings as we have seen. Finally, complementarity is to be seen as <u>an adaptable form rather than a fixed mold</u>. While the eleven points of definition are to be found at every level of application they cannot be imposed <u>a priori</u> and can only be compared and identified with the given features of each level individually. When we come to discuss the role of complementarity in theology, therefore, our principal concern will be to ask whether these eleven points have counterparts in the various theological doctrines and whether they are, in fact, comparable.

Footnotes: Chapter 3.

1. "The Quantum Postulate, etc.", p.590 = ATDN, p.101; cf. pp.96-101,117-119.

2. ATDN, p.20; cf. L.Rosenfeld, "Niels Bohr in the Thirties", p.116.

3. "...the gradual development of an appropriate terminology for the description of the simpler situation in physical science indicates that we are not dealing with more or less vague analogies, but with clear examples of logical relations which, in different contexts, are met with in wider fields." Essays, p.7; cf. pp.60,77-78, and ATDN, p.20.

4. The only published references are in Bohr's 1930 Faraday Lecture, "Chemistry and the Quantum Theory of Atomic Constitution" (J.Chem.Soc., 1932, Part 1, pp.376-377) and in his 1949 Steno Lecture, "Physical Science and the Problem of Life" (APHK, p.97). But Bohr often discussed the problem with his friends; see W.Heisenberg, Physics and Beyond, pp.105-107.

5. In classical thermodynamics and statistical mechanics this can be done exactly since there is no uncertainty principle.

6. "A typical example /of the recourse to probability considerations when there is no possibility of defining the initial conditions/ is afforded by the statistical theory of heat, according to which the very concept of temperature stands in an exclusive relation to a detailed description of the behavior of the atoms in the bodies concerned." "Chemistry and the Quantum Theory, etc.", p.376; cf. W.Heisenberg, op.cit., p.105.

7. See ch.2, fn.114 for references on the problem of time reversal.

8. "The peculiar contrast between the reversibility of simple mechanical processes and the irreversibility typical of many thermodynamic phenomena was thus clarified by the fact that the application of such concepts as temperature and entropy refer to experimental conditions incompatible with complete control of the motions of single molecules." APHK, p.97; cf. "Chemistry and the Quantum Theory, etc.", p.376.

9. ibid.

10. i.e. the velocity of molecules is uncorrelated with their position; see K.Huang, Statistical Mechanics, New York, 1963, p.65.

11. cf. W.Heisenberg, loc.cit.

12. See K.Huang, op.cit., pp.75-78,139-141.

13. Bohr's reasoning on this point is nicely clarified by J.L.Park, "Quantum Theoretical Concepts of Measurement", Phil.Sci. 35, 1968, p.219; cf. L.Rosenfeld, "Foundations of Quantum Theory and Complementarity", Nature 190, 1961, p.387.

14. These "ensembles" are not actual groups of systems that interact with each other; they are collections of identically prepared systems that are strictly isolated from one another. The systems of an ensemble need not be studied all at the same time or even exist at the same time, and an ensemble could simply consist of a single system prepared and studied at many different times; cf. K.Huang, op.cit., pp.75,76,141.

15. "Chemistry and the Quantum Theory, etc.", p.376. On the difference between the two approaches see E.T.Jaynes, "Foundations of Probability Theory and Statistical Mechanics", in M.Bunge, ed., Delaware Seminar in the Foundations of Physics, pp.77-101.

16. An uncertainty principle for temperature (representing the macrostate) and energy (representing the microstate) has been worked out by Rosenfeld in which Boltzmann's constant takes the place of Planck's constant in quantum theory; see his "Questions of Irreversibility and Ergodicity", in P.Caldirola, ed., Ergodic Theories, New York, 1961, pp.6-7.

17. For a qualitative analysis see W.M.Elsasser, Atom and Organism, Princeton, 1966, pp.79-81, and "The Mathematical Expression of Generalized Complementarity", J.Th. Biol. 25, 1969, pp.294-295; see below, ch.4.7.

18. Personal Knowledge, pp.390-393, esp. the footnote on p. 392 where Polanyi comments on Bohr's Faraday Lecture and takes exception to it; cf. J.R.Oppenheimer, Science and the Common Understanding, London, 1954, pp.83-87.

19. cf. Knowing and Being, p.174.

20. Essays, p.7; cf. fn.3 above.

21. cf. L.Rosenfeld, "Foundations of Quantum Theory, etc.", p.387.

22. See ch.1.2 above. Bohr's most important papers on biology are "Light and Life" (Nature 131, 1933, pp.421-423, 457-459, revised in APHK, pp.3-12), "Causality and Complementarity" (Phil.Sci. 4, 1937, pp.295-297), "Biology and Atomic Physics", (Nuo.Cim. n.s.15, 1938, pp.429-438, reprinted in APHK, pp.13-22), "Physical Science and the

Problem of Life" (delivered in 1949, revised in APHK, pp.94-101), "Quantum Physics and Biology", in Models and Analogues in Biology (Symposia of the Society for Experimental Biology, No.14), Cambridge, 1960, pp.1-5, "Physical Models and Living Organisms" (in W.E.McElroy and B.Glass, eds., A Symposium on Light and Life, Baltimore, 1961, pp.1-3), and "Light and Life Revisited" (delivered in 1962, reprinted in Essays, pp.23-29).

23. "In fact, we are led to conceive the proper biological regularities as representing laws of nature complementary to those appropriate to the account of the properties of inanimate bodies, in analogy with the complementary relationship between the stability properties of the atoms themselves and such behavior of their constituent particles as allows of a description in terms of space-time coordination." APHK, p.21; cf. pp.10,76, ATDN, pp.22-23, and "Causality and Complementarity", p.296, cf. L.von Bertalanffy, Problems of Life, London, 1952, p.155. Note that the concept of complementarity is now used analogically as are the concepts of atom and organism. The concept of "atom" is taken from ordinary language via metaphysics (Epicurean), classical physics and chemistry, and quantum physics. The concept of "organism" is taken from ordinary language via metaphysics (Aristotelian) and classical biology. But the concept of "complementarity" is taken from quantum physics alone and does not belong to our everyday concepts even though the word is taken from ordinary language; see ch.1, fn.110 and ch.2, fn.27.

24. "...there is set a fundamental limit to the analysis of the phenomena of life in terms of physical concepts, since the interference necessitated by an observation which would be as complete as possible from the point of view of the atomic theory would cause the death of the organism." ATDN, p.22; cf. APHK, pp.9,20,76,92,100.

25. "...the notion of life is elementary in biological science where, in the existence and evolution of living organisms we are concerned with manifestations of possibilities in that nature to which we belong rather than with the outcome of experiments which we can ourselves perform." APHK, p.76; cf. pp.9,101, and ATDN, p.23.

26. "I think we all agree with Newton that the real basis of science is the conviction that Nature under the same conditions will always exhibit the same regularities. Therefore, if we were able to push the analysis of the mechanism of living organisms as far as that of atomic phenomena, we should scarcely expect to find any features differing from the properties of inorganic matter." "Light and Life", p.458; cf. APHK, p.9, and "Causality and Complementarity", pp.295-297.

27. "The asserted impossibility of a physical or chemical explanation of the function peculiar to life would in

this sense be analogous to the insufficiency of the mechanical analysis for the understanding of the stability of atoms." "Light and Life", p.458; cf. APHK, p.9, and "Causality and Complementarity", p.295.

28. e.g. APHK, pp.21,62,76,92,100.

29. "Physical Models and Living Organisms", p.3.

30. APHK, p.8.

31. APHK, p.9.

32. Essays, p.27.

33. APHK, p.92.

34. ATDN, p.23.

35. APHK, p.10, Essays, p.21.

36. "...it is important to recognize that the essential element of irreversibility involved in the description of the organic functions is the very basis of our notion of time direction." "Physical Science and Man's Position", in Proceedings of the International Conference on the Peaceful Uses of Atomic Energy (Geneva, 1955), New York, 1956, pp.59-60; cf. APHK, p.100.

37. APHK, pp.10,92, Essays, p.21.

38. APHK, pp.10,92, Essays, p.26.

39. "Physical Models and Living Organisms", p.3.

40. APHK, pp.9,10,21,76, and Essays, p.26.

41. "Causality and Complementarity", p.296, and APHK, p.21; see ch.1.4 above. Unfortunately, critics have focused attention on the former; e.g. J.Needham, Order and Life, Cambridge, Mass., 1968.

42. See ch.1, fns.132,148 above.

43. "In a living organism, however, such a distinction between the measuring instruments and the objects under investigation can hardly be fully carried through, and we must be prepared that every experimental arrangement whose aim is a description of the functioning of the organism, which is well defined in the sense of atomic physics, will be incompatible with the display of life." APHK, p.92; cf. pp.10,20-21,92,100, and "Causality and Complementarity", p.296.

44. "The basis of the complementary mode of description in biology is not connected with problems of controlling the interaction between object and measuring tool, already taken into account in chemical kinetics, but with the practically inexhaustible complexity of the organism." "Physical Models and Living Organisms", p.3, cf. "Quantum Physics and Biology", p.5.

45. Essays, pp.20-21,27.

46. i.e. because the inhomogeneity makes each organism unique so that statistical methods cannot be applied at the atomic level as they can for thermodynamic systems. This argument was later amplified by W.M.Elsasser (The Physical Foundation of Biology, London, 1958, pp.150-160; see below, ch.4.7), but already in 1949 Max Delbrück attributed it to Niels Bohr with whom he had discussed the issue in 1937, over twenty years before Elsasser's work was published. Delbrück had decided to study biology after hearing Bohr's 1932 address on "Light and Life" and when he assumed the directorship of the new Institute for Genetics in Cologne in 1962 he invited Bohr to give the inaugural address on "Light and Life Revisited". See M.Delbrück, "A Physicist Looks at Biology", Transactions of the Connecticut Academy of Arts and Sciences 38, 1949, pp.173-190 (reprinted in J.Cairns et al., eds., Phage and the Origins of Molecular Biology, Cold Spring Harbor, 1966, pp.9-22), and "A Physicist's Renewed Look at Biology: Twenty Years Later" (Nobel Prize address, 1969), Science 168, 1970, pp.1312-1315; N.Bohr, "Light and Life Revisited", in Essays, pp.23-29; and L. Rosenfeld, "Niels Bohr in the Thirties", p.134.

47. cf. W.M.Elsasser, Atom and Organism, p.134.

48. "In the study of regulatory biological mechanisms the situation is rather that no sharp distinction can be made between the detailed construction of these mechanisms and the functions they fulfil in upholding the life of the whole organism. Indeed, many terms used in practical physiology reflect a procedure of research in which, starting from the recognition of the functional role of the parts of the organism, one aims at a physical and chemical account of their finer structures and of the processes in which they are involved. Surely, as long as for practical or epistemological reasons one speaks of life, such teleological terms will be used in complementing the terminology of molecular biology." Essays, p.26. Bohr might just as well have said that functionalism and structuralism represent "complementary viewpoints"; cf. A.Meyer-Abich, "The Principle of Complementarity in Biology", Acta biotheoretica 11, 1955, p.62; see ch.4.11 below. For the views of Niels's father on this subject see L. Rosenfeld, "Niels Bohr in the Thirties", p.132.

49. W.A.Cook, op.cit., pp.7,15; cf. ch.1. fn.151 above. The term "tagmeme" was coined by Bloomfield (Language, London, 1935, p.166) and adapted by Kenneth Pike ("Taxemes and Immediate Constituents", Language 19, 1943, pp.65-82; and "On Tagmemes, Née Gramemes", I.J.A.L. 24, 1958, pp. 273-278).

50. K.L.Pike, Language in Relation to a Unified Theory of the Structure of Human Behavior, The Hague, 1967.

51. For the rules governing the formation of these equations, see W.A.Cook, op.cit., pp.17ff. The colon between the functional and structural terms means "filled by" or "fulfilled by the class of".

52. The period of time needed for this alternation must be smaller than the threshold for reflex action or even subliminal vision. The alternation itself cannot be observed because all physical observations involve interaction at the molecular level and are limited to the surface layer of the organism.

53. A similar hierarchy of biological levels is proposed by J.H.Woodger in his Biological Principles, London, 1929, pp.308-317. Like Bohr, Woodger stresses the change that takes place in any 'part' when it functions within the 'whole' as well as the necessity for investigating each level of organization on its own terms.

54. Brief comments on psychology appear in almost all of Bohr's writings. The three principal references are "Wirkungsquantum und Naturbeschreibung" (Naturwis. 17, 1929, pp.483-486, translated in ATDN, pp.92-101), "Unity of Knowledge" (in L.G.Lewis, ed., The Unity of Knowledge, New York, 1955, pp.7ff, reprinted in APHK, pp.67-82), and "The Unity of Human Knowledge" (delivered in 1960, reprinted in Essays, pp.8-16).

55. "Every unambiguous communication about the state and activity of our mind implies, of course, a separation between the content of our consciousness and the background loosely referred to as 'ourselves', but any attempt at exhaustive description of the richness of conscious life demands in various situations a different placing of the section between subject and object." Essays, pp.12-13; cf. APHK, pp.52,77,93. For the analogy to atomic physics see "Newton's Principles, etc.", p.60, and "Physical Science and the Study of Religions", p.389.

56. "The rich vocabulary used in the communications of the states of our mind refers indeed to a typical complementary mode of description corresponding to the continual change of the content on which attention is focused." APHK, p.101. On Bohr's use of an analogy to Riemann's treatment of multiform complex functions, see L.Rosenfeld, "Niels Bohr's Contribution to Epistemology", p.49.

57. APHK, p.77; see ch.1, fn.43 on William James's theory of hysteric diseases.

58. ATDN, p.15, "Causality and Complementarity", p.297, APHK, pp.21,27. On Bohr's dialectic of the necessity and impossibility of a sharp distinction, see p.20 above.

59. For the analogy to atomic physics, see ATDN, p.100, and APHK, p.11.

60. "We all know the old saying that, if we try to analyze our own emotions, we hardly possess them any longer, and in that sense we recognize between psychical experiences, for the description of which words such as 'thoughts' and 'feelings' are adequately used, a complementary relationship similar to that between the experiences regarding the behavior of atoms obtained under different experimental arrangements and described by means of different analogies taken from our usual ideas." APHK, p.27; cf. Essays, p.14.

61. "Thus, words like contemplation and volition, referring to situations which are mutually exclusive but equally characteristic of conscious life, have been used in a typical complementary manner since the very origin of language." Essays, pp.21-22; cf. p.13, and APHK, pp.21, 77,93.

62. APHK, pp.79-80, and Essays, p.15; cf. A.Koestler's polarity between the "logic of laughter" and the "logic of the moist eye"; The Act of Creation, London, 1964.

63. e.g. APHK, pp.21,27,52,93, and Essays, p.28.

64. "This use of concepts, in fact, not only is to a large extent suppressing instinctive life, but it stands even largely in an exclusive relationship of complementarity to the display of inherited instincts." APHK, p.28; cf. pp.27,76; and T.R.Blackburn, "Sensuous-Intellectual Complementarity in Science."

65. APHK, pp.80-81; cf. "Physical Science and the Study of Religions", p.386; and W.Heisenberg, Physics and Beyond, p.90.

66. Personal Knowledge, p.55, Knowing and Being, pp.128,146; cf. de Saussure's distinction between the receptive side (la langue) and the executive side (la parole) of the psychological circuit of speech (Course in General Linguistics, New York, 1959, p.13). The langue-parole duality was later reinterpreted to signify the complementarity between psychical ideas and physical sounds or between phonology and phonetics (see de Saussure, op. cit., pp.111ff; and S.Ullmann, The Principles of Semantics, Oxford, 1957, pp.28ff,39f). The original distinction corresponds to Bohr's "subjective" use of complementarity in psychology, and the later one to his "objective" use. On the relation between the two see below, p.105f. R.Jakobson has suggested that the relationship between 'encoding' (meaning to sound) and 'decoding' (sound to meaning) in communication theory is one of 'complementarity' in Bohr's sense; see his "Linguistics and Communication Theory", Proceedings of Symposia in Applied Mathematics 12, 1961, p.249.

67. J.Dewey, "The Reflex Arc Concept in Psychology", Psychological Review, 3, 1896, p.370.

68. J.von Uexküll, Umwelt und Innenwelt der Tiere, Berlin, 1921; cf. E.Cassirer, An Essay on Man, New Haven, 1944, ch.2.

69. J.C.Dollard and N.E.Miller, Personality and Psychotherapy, New York, 1950, pp.98-100.

70. cf. E.Cassirer, An Essay on Man, ch.2.

71. L.S.Vygotsky, "Thought and Speech", Psychiatry 2, 1939, pp.37-42, Thought and Language, Cambridge, Mass., 1965, pp.11-20,130-138; for a recent review see A.N.Sokolov, Inner Speech and Thought, New York, 1972, esp. pp.46ff.

72. J.Piaget, The Language and Thought of the Child, London, 1926. Piaget later revised this opinion: see Comments on Vygotsky's Critical Remarks, Cambridge, Mass., 1962.

73. "...it must not be forgotten that, in associating the psychical and physical aspects of existence, we are concerned with a special relationship of complementarity which it is not possible thoroughly to understand by one-sided application either of physical or of psychological laws." ATDN, p.24; cf. pp.100,101, and APHK, p.11. On Bohr's interest in Spinoza see L.Rosenfeld, Niels Bohr: An Essay, p.12, and "Niels Bohr's Contribution to Epistemology", p.48. Unfortunately, von Neumann later interpreted the subject-object relation as a "psychophysical parallelism", thus confusing correspondence with complementarity (see above, pp. 24-25), and cited one of Bohr's statements as a precedent (Mathematical Founations of Quantum Mechanics, pp.418-420, esp.fn.207; cf. ATDN, pp.100-101). As a result, many subsequent writers have interpreted Bohr's concept of complementarity in terms of von Neumann's subjective measurement theory; see e.g. P.A.Heelen, Quantum Mechanics and Objectivity, The Hague, 1965, pp.47,57-58. On the differences between Bohr and von Neumann see ch.2, fn.69 above.

74. ATDN, pp.24,100,117, "Newton's Principles, etc.", p.60, and "On the Notions of Causality and Complementarity", p.318.

75. ATDN, p.24, and APHK, pp.11,78.

76. "The decisive point is that, if we attempt to predict what another person will decide to do in a given situation, not only must we strive to know his whole background including the story of his life in all respects which may have contributed to form his character, but we must realize that what we are ultimately aiming at is to put ourselves in his place." APHK, p.78.

77. W.Dilthey, Einleitung in die Geisteswissenschaften (Gesammelte Werke, Band I), Leipzig-Berlin, 1923, pp.32-33.

78. The Tacit Dimension, pp.16-17, Knowing and Being, pp.152, 219-220,238.

79. cf. Bruno Bettelheim's thesis that "...the more the object of the study is man himself, and not just some isolated aspects of his behavior, the more questionable the value of the experimental method. The human mind is so complex that experiment can still clarify only some rather simple aspects of its working. If we wish to understand the human being in all his intricacy, we must fall back on the earliest method for comprehending man: to know oneself so that one may also know the other." B.Bettelheim, The Empty Fortress, New York, 1967, p.3.

80. The "from-at" relation is perpendicular to complementarity; see above p.24 and ch.2, fn.133.

81. We also use the terms "mind" and "body" analogically since they no longer have their strictly classical senses (which presuppose some classical theory like dualism or epiphenomenalism). The term "complementarity" is also being used analogically being taken from quantum physics via complementarist biology; see fn.23 above.

82. For a similar analysis of the modal structure of man see C.Robinson, "Biblical Theism and Modern Science", J.Rel. 43, 1963, p.126; and B.J.F.Lonergan, Insight, London, 1957, chs. xv.7.4 and xvi.4.3.

83. In fact, the four modes must alternate in time in accordance with the hierarchical structure of their relations. The alternation, itself, is unobservable (by definition, see fn.52 above), but it is consistent with theoretical formulations like the "perceptual moment" hypothesis of J.M.Stroud ("The Fine Structure of Psychological Time", in H.Quastler, ed., Information Theory in Psychology, Glencoe, Illinois, 1955, pp.174-207, and its sequel in R.Fischer, ed., op.cit., pp.623-631). According to this hypothesis, normal conscious perception takes place in separate "moments" of about one tenth of a second each. From the viewpoint of complementarity, this interval is readily understood as the relaxation time of the mind-body alternation. Of course, the relaxation times for the various levels of the atom-organism hierarchy would be much shorter than 0.1 sec, decreasing all the way to 10^{-8} sec, the characteristic time for the wave-particle alternation of atomic transitions. This whole subject is still rather speculative, but for partial confirmation of the hierarchical ordering of time scales in physiology and psychology see U.Neisser, Cognitive Psychology, New York, 1967, pp.18ff,36ff,138ff; and F.Smith, Understanding Reading, New York, 1971, pp.90-95, esp. ref.5 on p.95.

84. e.g. unconscious, preconscious, and conscious mind. For a possible development of this idea see R.Fischer, "A Cartography of the Ecstatic and Meditative States", Science 174, 1971, pp.897-904.

85. See above, pp.22f.

86. The term "idea" is used here in its broadest sense to include all mental phenomena. It may be a feeling evoked by a work of art or a belief associated with a sacred text.

87. P.A.Heelen has applied this use of complementarity to the philosophical problems of hermeneutics; see his "Towards a Hermeneutic of Natural Science", Main Currents in Modern Thought 2, 1972, pp.85-93, and "Nature and Its Transformations", Theological Studies 33, 1972, pp.492, 495.

88. The classic study on this topic is W.Köhler's The Mentality of Apes (New York, 1925). For a review of recent research see L.E.Jarrard, ed., Cognitive Processes of Nonhuman Primates, New York, 1971.

89. See below, ch.6.5 and ch.8.

90. cf. Marcel's distinction between body-as-existent (incarnate) and body-as-object (disincarnate) (Metaphysical Journal, London, 1952, pp.19ff,264,273-282,315f,332-339) and Sartre's distinction between body pour soi and body pour autrui (L'Être et le Néant, Paris, 1943, pp.198ff, 365ff); cf. R.M.Zaner, The Problem of Embodiment, pp. 89f,107ff,120ff.

91. So M.Eliade differentiates between classical yoga and shamanism (Le Chamanisme et les Techniques Archaïques de l'Extase, Paris, 1951, p.374; cf. R.C.Zaehner, Mysticism Sacred and Profane, Oxford, 1957, p.128); cf. N.Smart's distinction between dhyana and bhakti (The Yogi and the Devotee, London, 1968).

92. cf. Karl Popper's "third world" (Objective Knowledge, London, 1972) which, however, includes artifacts as well as ideas.

93. Not quite the same as Teilhard's "noosphere" which is a structural layer of the earth rather than a mode of man's existence; see The Phenomenon of Man, London, 1970, pp.201-202, and Man's Place in Nature, London, 1971, p. 80. Note that Teilhard's approach is thoroughly diachronic while Bohr's, though allowing for diachronic categories, is primarily synchronic; it allows for evolution but says nothing positive about it; see "Physical Models and Living Organisms", p.3.

94. In quantum theory a group of N particles may be treated either in terms of a single wave in 3N-dimensional "configuration space" or (by means of second quantization) in terms of N distinct waves in ordinary three-dimensional space (see e.g. L.de Broglie, "Individualité et Interaction dans le Monde Physique", Rev.Mét.Mor. 44, 1937, p.360; M.Born, "Bemerkungen zur statistischen Deutung der Quantenmechanik", in F.Bopp, ed., op.cit., p.105; and W.T.Scott, Erwin Schrödinger, Amherst, 1967, pp.77-

80). The Einstein-Podolsky-Rosen paradox (loc.cit.) showed that when one of these particles is observed, the others are automatically affected as well. It is conceivable that these considerations could also be applied to groups of systems in "thermodynamic space" (pressure, volume, temperature), "organismic space", and even "mental space" (cf. topos noetos) although the application could only be heuristic in the latter two instances.

95. cf. Polanyi's concept of "risk": Personal Knowledge, p.313.

96. cf. P.L.Berger and T.Luckmann, op.cit., pp.49ff,173. Note that Bohr's assumption of a common conceptual framework in science (ch.1.4 above) is here validated on the basis of complementarity in psychology.

97. I.I.Mitroff, "Solipsism: An Essay in Psychological Philosophy", Phil.Sci. 38, 1971, pp.376-394.

98. See above, ch.2, fn.80.

99. This may not apply to animals in a laboratory.

100. This correlation or propriety is not to be confused with determinism (see p.65, above). What we have here is the emergence of normative behavior ("ought"), not programmed behavior ("must").

101. "...amplification effects similar to those permitting observation of individual atomic particles play a decisive role in many functions of the organism. In this way is stressed the irreversible character of typical biological phenomena, and the time direction inherent in the description of the functioning of organisms is strikingly marked by their utilization of past experience for reactions to future stimuli." APHK, p.100; cf. p.77; and W.M.Elsasser, Atom and Organism, p.82.

102. See V.Lossky, The Mystical Theology of the Eastern Church, Cambridge, 1957, pp.123,174.

103. This process of 'internalization' takes place during 'primary socialization'; see P.L.Berger and T.Luckmann, op.cit., pp.149-157.

104. N.Brody and P.Oppenheim call it "structural homology": loc.cit., pp.97,111.

105. For parallels to ideas (2), (3), and (4) in general system theory see von Bertalanffy's principles of "logical homology", "hierarchical order", and "progressive individualization" (L.von Bertalanffy, General System Theory, London, 1973, pp.85,74f,72f, respectively).

106. The principal reference is "Natural Philosophy and Human Cultures", Nature 143, 1939, pp.268-272 (reprinted in APHK, pp.23-31).

107. e.g. APHK, p.30.

108. APHK, p.81, and Essays, p.15.

109. APHK, p.30.

110. e.g. T.Boman, Hebrew Thought Compared with Greek, London, 1960, pp.207-208. Different biographical interpretations of Einstein are regarded as complementarity by G.Holton, "On the Origins of the Special Theory of Relativity", Am.J.Phys. 28, 1960, pp.632-633.

111. e.g. APHK, p.81.

112. APHK, pp.30-31,81, and Essays, p.15.

113. APHK, pp.81,93.

114. contra A.Landé, New Foundations of Quantum Mechanics, Cambridge, 1965, p.146. Other counterexamples (duality, orthogonality and supplementarity) have been discussed in ch.2. On the other hand, the concept of complementarity might be useful in discussions of method in social anthropology, particularly with regard to the relation between fieldwork and structural analysis; see E.E.Evans-Pritchard, Social Anthropology, London, 1951, p.61.

115. "Atomic Physics and International Cooperation", p.138, "Physical Science and the Study of Religions", p.389, APHK, p.81, Essays, p.15.

116. I am not sure which myths Bohr had in mind. Perhaps he was thinking of the ancient Zoroastrian dualism between good and evil which was portrayed as an eternal struggle between Ahura Mazda (or Spenta Mainyu) and Angra Mainyu (see e.g. R.Masani, Zoroastrianism, New York, 1968, pp. 65-69). More likely he was referring to the confrontation between the Lord and Mephistopheles in Goethe's Faust, a play with which Bohr was quite familiar; see S.Rozental et al., op.cit., p.236.

117. Only W.H.Austin has taken the idea seriously, and he concedes that this "complementarity" applies only to religious experience and not to systematic theology: Waves, Particles and Paradoxes, p.93; see below, ch.6.4.

118. e.g. N.F.S.Ferré, The Christian Understanding of God, London, 1951, pp.114ff.

119. So the Hebrew prophets, e.g. Hosea 6. On the bifurcation of justice and mercy in Reformed theology see H. Rolston III, John Calvin Versus the Westminster Confession, Richmond, Va., 1972, ch.5.

120. Private communication to G.J.Holton, Dec.25,1967; see G.J.Holton, "The Roots of Complementarity", p.1044.

121. APHK, p.47.

122. J.Baillie, Our Sense of the Presence of God, (Gifford Lectures, 1961-2), London, 1962, p.217; cf. W.G.Pollard, Chance and Providence, London, 1958, p.139 (the citation here of Bohr's article "On the Notions of Causality and Complementarity" is mistaken), and "Indeterminacy, Mystery, and a Modern Epistemology", Zygon 1, 1966, p. 181. Bohr's Gifford Lectures on "Causality and Complementarity" were given at the University of Edinburgh from October 21 to November 11, 1949 (see the advertisement in Nature 164, 1949, p.561) but never published. On the preparation and delivery of these lectures, see S.Rozental, "The Forties and Fifties", in S.Rozental et al., op.cit., pp.182f.

123. Zum Weltbild der Physik, Stuttgart, 1960, p.256; cf. J.R.Oppenheimer, op.cit., pp.74-75.

124. e.g. N.F.S.Ferré, op.cit., pp.71-85; K.Barth, Church Dogmatics, III.2 (Edinburgh,1960), ch.47.1, p.437; and S.M.Ogden, "The Temporality of God", in The Reality of God and Other Essays, New York, 1966, pp.144-163; cf. ch.7.3(6) below.

125. "From this point of view we realize that Bohr's proposal of the complementarity principle was nothing less than an attempt to make the cornerstone of a new epistemology ...it was the universal significance of the role of complementarity which Bohr came to emphasize." J.G. Holton, loc.cit., p.1045; cf. fn.3 above.

Chapter 4

Bohr's Allies on Complementarity

> "For the 'Copenhagen Point of View' as it is understood by some critics, and, one must admit, by some of its adherents, is not a single idea but a mixed bag of interesting conjectures, dogmatic declarations, and philosophical absurdities..." P.K.Feyerabend, "On a Recent Critique of Complementarity I", p.310.

Having established Bohr's own views on complementarity, we turn now to those of his allies and critics. Our focus will be on the contributions they make either by way of coherent formulations, or of new applications, or of significant criticisms. However, we shall also have to consider alternative definitions of complementarity and numerous misunderstandings of Bohr in order to clear up the confusion and sharpen our understanding of Bohr's own position. The general philosophies of the men we study will be brought in only insofar as it is necessary to interpret their statements on complementarity.

The division into allies and critics is somewhat arbitrary, as we shall see. Bohr's critics are often closer to his intent than his supposed allies. However, the distinction is helpful in that it coincides with the general cleavage among modern physicists between the so-called "Copenhagen school" and its numerous opponents.

The order in which we treat Bohr's allies is roughly the order of decreasing personal contact with Bohr himself. Therefore, we might expect that those treated first would have a better understanding of Bohr's position than those that follow. As it turns out, however, this expectation is only approximately correct.

4.1 Léon Rosenfeld:

Rosenfeld worked more closely with Bohr than anyone else,[1] and no one has championed Bohr's ideas, especially complementarity, more outspokenly.[2] His definition of complementarity is concise and to the point: "a logical relationship between two physical phenomena both representing aspects of a physical system equally necessary for its complete description, but corresponding to mutually exclusive experimental conditions".[3] This definition covers the conditions of unity, equality, coexhaustiveness, and mutual exclusion. Elsewhere, Rosenfeld defines complementarity in terms of reciprocity.[4] At times, however, he seems to suggest that the two modes of wave and particle are equivalent pictures since the wavelength and frequency of a wave are directly related to the momentum and energy of the corresponding "particle", thus confusing complementarity with supplementarity.[5] Thus he represents quantum theory as achieving a synthesis between the classical concepts of force (field, wave) and matter (particle).[6] But here, one suspects, his philosophical commitment to dialectical materialism begins to conflict with his allegiance to Bohr.[7] He sees complementarity as representing the final stage of <u>synthesis</u> in the "dialectical movement of scientific thought": classical determinism (material particles) was the <u>thesis</u> which was negated by the discovery of the quantum of action, and the "old quantum theory" (Bohr's 1913 model which introduced stationary states) was the antithesis.[8] All of this has nothing to do with the philosophy of Bohr; still it is significant that the leading exponent of Bohr's thought is neither a Kantian idealist nor a logical positivist.[9]

Rosenfeld applies the concept of complementarity to thermodynamics and biology as well as atomic physics (he stopped short of psychology), but here too the concept of supplementarity prevails. He regards the emergence of characteristically thermodynamic features like irreversibility as being due solely to our ignorance of the microscopic initial conditions; statistical regularities do not replace the laws of molecular dynamics, they are simply superimposed on them.[10] Hence, an imaginary demon ("Maxwell's demon") small enough to observe the motions of the individual molecules would find that reversibility holds at the microscopic level even while we are experiencing irreversibility at the macroscopic level.[11] Of course, this would make complementarity completely subjective, a matter of observation rather than definition.[12] But fortunately, according to Rosenfeld, such a demon could never exist as it is a self-contradictory concept: the ability to think and observe requires a complex brain (from the viewpoint of materialism) so a thinking being must be macroscopic by definition.[13] This inherent limitation assures us that our science is objective in the sense that intelligent beings from another planet would necessarily be subject to the same limitation and hence would also observe effects like irreversibility.[14] An argument more in line with Bohr's epistemology would be that the very conditions necessary for the definition of Maxwell's demon exclude those for the definition of thermodynamic states. Hence the two can not exist at the same time and do not contradict each other.[15]

The same difficulty arises in Rosenfeld's treatment of biology. In contrast to Bohr, Rosenfeld expects that all biological behavior will one day be explained, in principle, by the laws of quantum mechanics, just as chemistry is.[16] However, he argues, even when this reduction is achieved complementarity will not be eliminated because (a) organisms are so complex in their <u>structure</u> that a complete quantum-mechanical treatment would be impossible in practice, and (b) we must know the <u>function</u> of an organ before we can understand its structure.[17] Since the concept of function is absent from physics and chemistry (according to Rosenfeld), there is a relationship of complementarity between the "functional causality" of biology and the ordinary causality of physics and chemistry.[18] As we have seen, Bohr also argued for complementarity on the basis of complexity and the irreducibility of function, yet his reasoning was really quite different. For Bohr: (a) the complexity of organisms, together with their inhomogeneity, makes definition of the molecular structure impossible in principle, not just in practice,[19] and (b) fuhction and structure represent complementary modes which are individually complete and mutually exclusive; hence function is not simply an auxiliary idea that is superimposed to complete a physico-chemical description as it is for Rosenfeld.[20]

The hierarchical relation of complementarity in atomic physics, thermodynamics and biology is brought out by Rosenfeld. For individual atomic systems only the wave-particle complementarity is applicable. Thermodynamic complementarity arises for systems of large numbers of atoms (on the order of Avogadro's number, 6.2×10^{23}), and it is completely independent of the existence of complementarity at the atomic level.[21] Finally, biological complementarity arises for systems of great complexity, both in molecular structure and in the topological arrangement of molecules.[22] Thus thermodynamics and biology represent two different directions of emergence above the atomic level as we have seen.[23] Again, however, for Rosenfeld the emergent qualities are simply superimposed upon the atomic level; they do not represent independent levels in their own right.

4.2 Wolfgang Pauli:

Next to Rosenfeld, those closest to Bohr were Wolfgang Pauli and Werner Heisenberg.[24] According to Rosenfeld's report, Bohr respected Pauli's opinions most of all, and "no one better than Pauli understood the earnestness of Bohr's endeavour".[25] When we examine Pauli's writings, however, we find very little in common with "Bohr's endeavour".[26] Pauli consistently maintained that complementarity is due to the uncontrollable interference (Eingriff) involved in the measuring process which invalidates the results of all previous measurements.[27] For instance the value obtained from a momentum measurement is invalidated by any subsequent measurement of the position of an atomic object, hence the uncertainty principle. All of this is true, of course, but it is not an adequate basis for complementarity since it is limited to the possibilities of measurement and neglects the possibilities of definition which Bohr stressed. In fact, Bohr specifically warned against using terms like "disturbance" and "interference" in any unambiguous account of the measuring process.[28]

Pauli frequently used the term "complementarity" in ways that are at variance with Bohr's position. For instance, he refers to complementarity between the classical concepts of position and momentum (rather than conjugacy)[29], between mutually exclusive experimental arrangements,[30] and even between the means of observation and the object observed (rather than correspondence).[31]

It is not surprising, therefore, that Pauli differs with Bohr when it comes to the application of complementarity outside of atomic physics. He completely rejects Bohr's treatment of thermodynamics[32] and ignores his treatment of biology and turns instead to metaphysics and psychoanalysis: (a) In metaphysics Pauli sees a relationship of complementarity between the extremes of Western realism, in which physical objects are completely independent of the manner in which they are observed, and Hindu idealism, in which there is an absolute subject and no independent object.[33] It is true that Bohr also sought a middle path between realism and idealism, but he would hardly have called this a relationship of complementarity, even in the sense of a relationship between different cultural traditions.[34] (b) When Pauli turns to psychoanalysis he finds that the unconscious self is complementary to the conscious self since it cannot be observed directly but only through indirect means that circumvent the conscious self (e.g. dreams, free association, etc.).[35] The principle issue for us here is whether the conscious and unconscious aspects of mind are mutually exclusive in reality as well as in our experience. In order to settle this issue one must consider the possibilities of definition as well as those of observation, and for this one needs a psychological model. In the traditional Freudian and Jungian models the conscious mind is superimposed on the unconscious,[36] so the two would not be complementary in the strict sense. A complementarist model would require some kind of alternation between the two modes so that the two never actually conflict. No such model has been constructed, to my knowledge, however it remains a possibility for the future.[37] Traditional Freudian (or Jungian) psychoanalysis could be used as a "classical model" and the concepts of conscious and unconscious could be reinterpreted analogically in keeping with the correspondence principle.[38]

4.3 Werner Heisenberg:

The principle of complementarity is closely related to the uncertainty principle, as we have seen.[39] In fact, both principles were developed at the same time, during February of 1927, while Bohr and Heisenberg were working together on the problems of the interpretation of quantum theory.[40] Yet the methods and starting points of the two men were poles apart. Heisenberg valued mathematical elegance and simplicity above all, while Bohr concentrated on physical principles and questions of method.[41] It is not surprising, therefore, that their interpretations of complementarity were entirely different.[42]

Their common point of departure was the complementarity of space-time coordination and the claim of causality. Bohr used these two concepts to represent two modes, wave and particle, of an atomic system. The particle-mode applies when the space-time locations of the individual particles of the system are observed, and the wave-mode applies when the system is relatively isolated so that the conservation laws and the claim of causality are suitably defined.[43] Heisenberg replaced the physical idea of a wave-mode by the mathematical wave-function and the transition to the particle-mode by the "collapse" or "reduction" of the wave-function.[44] Since the wave-function obeys Schrödinger's equation its evolution is perfectly <u>causal</u> and hence "<u>objective</u>" (i.e. independent of human perception), but it is <u>unobservable</u> since it is defined in a multi-dimensional configuration space rather than in the geometric space of ordinary experience.[45] Its only connection with ordinary space and time is statistical: it determines the probabilities of the various space-time events that might occur when the system is observed and the wave-function collapses.[46] Thus, while the wave-function is perfectly objective (in Heisenberg's sense), it is <u>not real</u>; it is only an "objective tendency" or "potential for reality" or, in Aristotelian language, a <u>potentia</u> or <u>dunamis</u>.[47] Space-time events, on the other hand, are actual occurrences that are <u>real</u> and <u>observable</u>, but they are also <u>acausal</u> and partly <u>subjective</u> because they involve our perception of the atomic system rather than the system as it is "in itself",[48] and the transition from the potential to the actual involves a disturbance of the system through measurement which, in effect, creates its observable qualities.[49] Hence, we are left with a relationship of "complementarity" between classical description in terms of space-time events which are actual and observable, but acausal and subjective, and a quantum-mechanical description in terms of wave-functions in configuration space which are unobservable and potential, but causal and objective.[50] In effect, Heisenberg creates a Kantian dichotomy between the phenomena and the noumena, or between the "thing-for-us" and the "thing-in-itself".[51] Rather than Bohr's complementarity between two modes of the object as it exists under different circumstances (ontological or transverse complementarity), we have complementarity between the object as it appears when observed and as it is in itself (epistemological or longitudinal complementarity). How could such a reversal of Bohr's position ever have happened?

First we must note that there is an asymmetry between the two modes in Bohr's thinking: one represents the ideal of observation and the other the ideal of definition. The stable wave-mode requires a greater degree of isolation and independence than the unstable particle-mode.[52] Therefore, Heisenberg's Kantian interpretation might seem to be a natural development of Bohr's concept provided that the two essential points were overlooked: (1) In Bohr's ontology there is no such thing as an isolated object in the strict sense. Every object has an environment and the specification of this environment is essential to an adequate knowledge of the object itself whether it interacts strongly with its environment or not.[53] Heisenberg considered only the possibilities of observation and neglected the possibilities of definition.[54] (2) The wave-mode can be known just as well as the particle-mode can. The only restriction is that it cannot be known directly or specifiably, but only indirectly and tacitly.[55] In general, however, it was due to Bohr's emphasis on physical principles that he avoided Kantian dualism. Heisenberg thought in terms of an abstract mathematical formalism, and this naturally led him to conceive the wave-mode as an abstract, unobservable <u>Ding an sich</u> rather than a mode of existence in Bohr's sense.[56]

4.4 Carl Friedrich von Weizsäcker:

From his personal association with Bohr, Pauli and Heisenberg, von Weizsäcker could see the differences in their concepts of complementarity, and he tried to classify and interrelate them in his own approach to the subject.[57] He divided them into two categories which he called "parallel complementarity" and "circular complementarity".[58]

"Parallel complementarity" holds between two concepts which are both derived from classical physics and hence belong to the same conceptual level. For instance: (a) There is "complementarity" between the classical particle concepts of position and momentum. This is what Bohr called "conjugacy" and Pauli called "complementarity".[59] In the terminology of predicate calculus, it is complementarity between two predicates of the same subject. The two statements, "this electron has the position x" and "this electron has the momentum p", are complementary in this sense.[60] (b) There is also "complementarity" between the classical wave concepts of position and wavelength as Bohr pointed out in his treatment of the uncertainty principle.[61] The term "position" here means the location of a wave-group (in quantum-mechanics the region in which there is a significant probability of finding the particle), which is quite different from the meaning of "position" for a classical particle. (c) Finally, there is "complementarity" between (a) and (b), that is, between the classical pictures of particle (with position and momentum) and wave (with position and wavelength). This is the relationship we have previously referred to as "supplementarity" or "equivalence".[62] Von Weizsäcker points out that the Heisenberg-Schrödinger quantum mechanics is derived by quantizing the classical theory of particles while the quantum field theory is derived by quantizing the classical theory of fields. Since quantum mechanics and quantum field theory are equivalent theories, the two limiting cases from which they are derived are also equivalent pictures.[63]

None of these senses of "parallel complementarity" is the sense in which Bohr used the term, von Weizsäcker argues. As we saw in chapter two, Bohr's complementarity is not between conjugate properties or between equivalent pictures, but between alternate modes in which the conjugate properties are well-defined. According to von Weizsäcker, however, Bohr's complementarity was yet another relation, that between the two <u>classical pictures</u>, on the one hand, and the <u>quantum-theoretical formalisms</u> derived from them, on the other.[64] This "circular complementarity", as he calls it, is clearly Bohr's concept of correspondence, however, and is quite distinct from his idea of complementarity.[65] But why did von Weizsäcker get the two mixed up?

There are two reasons: (1) First he misunderstood Bohr's use of complementarity between space-time coordination and the claim of causality as a relationship between classical-mechanical description and quantum-mechanical description just as Heisenberg did.[66] When Bohr later rejected this interpretation in private correspondence, von Weizsäcker even admitted that he had based his interpretation of Bohr on the writings of Heisenberg though he refused to alter his approach.[67] Heisenberg and von Weizsäcker shared a Kantian epistemology which gave them a greater affinity for each other than either man had for Bohr.[68] (2) Secondly, von Weizsäcker confused complementarity between application and analysis with the circular relationship between _a priori_ assumptions, which allow us to apprehend reality, and _a posteriori_ knowledge from experience, which allows us to revise our assumptions. He called this the "circle of knowledge" (_Zirkel der Erkenntnis_) from which he got the term "circular complementarity".[69] Two of Bohr's ideas are cited as precedents: the complementarity between the application of a concept and its strict definition,[70] and complementarity between our empathetic, subjective understanding of life processes (_Verstehen_) and an objective analysis in terms of physics and chemistry (_Erklären_).[71] In both of these cases our knowledge seems to progress by an alternation between the two poles, one tacit and the other specifiable. However, for Bohr, it is not just our knowledge of the object, but the object itself, that evolves by an alternation between modes.[72] Von Weizsäcker is thinking of a subjective "gestalt-switch", whereas Bohr intended an objective "mode-switch".[73] Of course, Bohr also believed that the human mind undergoes "mode-switches" as it alternates between application and analysis, subsidiary awareness and focal awareness,[74] but this "circle of knowledge" in the mind is quite distinct from the "cycle of being" in the external world. Von Weizsäcker's mistake here was to transfer complementarity from the modes of an object (ontological or transverse complementarity) to the poles of our knowledge of that object (epistemological or longitudinal complementarity).[75] The result is a Kantian relationship between our forms of perception or the object as we perceive it and the object as it is in itself.[76]

Von Weizsäcker's other main contribution to the study of complementarity is his work on a formal, multi-valued "logic of complementarity" (Komplementaritätslogik).[77] The novel feature of this logic is the introduction of a third truth value, "undecided" or "indeterminate". A statements need not be either true or false; it may be undecided. For instance, the statement, "this electron has position x", is either true or false when the electron is in the particle-mode, but it is undecided or indeterminate in the wave-mode. Conversely, the statement, "this electron has momentum p", is undecided in the particle-mode. A symbolic logic can be developed, and it turns out to have several interesting features. For example, the statement, "s is not true", does not entail "s is false" as it does in classical logic because s could also be "undecided". This "logic of complementarity" is also non-truth-functional since the truth value of a compound statement is not necessarily determined by the truth values of its components. It is also non-tautologous since even the classically tautologous disjunction of "s is true" and "s is false" is not true when s itself is undecided. Further, the two distributive laws are not satisfied as they are in classical logic.[78]

Bohr himself had no interest in the development of a formal logic partly because he was suspicious of formal systems in general,[79] but particularly because he insisted on the use of classical (the refinement of ordinary) language and logic in all discussions of experimental method.[80] According to the correspondence principle, one is free to use non-classical systems of logic only insofar as those systems can be properly defined by making use of classical logic so the difficulties of interpretation cannot be circumvented simply by inventing a new logic. Classical logic can never be entirely supplanted because it is the foundation of all modern logic and it cannot be reduced to a mere limiting case.[81] Von Weizsäcker, on the other hand, maintained that multi-valued logic is the "true logic" (<u>die wahre Logik</u>) and that classical logic is only one of its many limiting cases, the relationship of the two being another example of "circular complementarity".[82] These issues could be debated at great length, but the recurrent theme would continue to be the nature of the classical forms of perception. If these are basically arbitrary then reality will forever elude us no matter how much we try to remold them, but if they are essentially valid then we have already made contact with reality and all that is needed is further exploration of this reality and the discovery of new aspects by using and building upon the conceptual tools or forms of perception that we already have.[83]

4.5 Max Born:

We turn now to the Göttingen school of physicists headed by Max Born. It was at Göttingen that de Broglie's idea of electron waves was first verified (by Elsasser),[84] that the formalism of matrix mechanics was developed (by Born and Jordan),[85] and that the statistical interpretation of the wave-function was discovered (by Born).[86] There was a good deal of cooperation between the physicists at Copenhagen and Göttingen, and the philosophy of quantum mechanics that developed became known as the "Copenhagen interpretation" only out of deference to the leadership of Niels Bohr.[87]

Born readily acknowledged that leadership, particularly with regard to the philosophy of quantum mechanics and the principle of complementarity.[88] According to Born, Bohr was neither a positivist nor an idealist, but a naive realist due to his concern for unambiguous communication and the use of ordinary language and his emphasis on physical intuition rather than mathematical formalism.[89] In contrast, he took Einstein to be a conventionalist like Poincaré because of his insistence that all concepts are free inventions of the mind![90] In view of Born's personal acquaintance with both of these men it is surprising that he understood them so little.

Born's scattered comments on complementarity can be very confusing and even contradictory on first reading. To avoid confusion one should note his distinction between "complementarity" and "duality"[91] and his use of the terms "wave" and "particles" to mean wave-function (or "probability wave") and particle-events.[92] Duality: Born regards the relationship between wave (function) and particle (events) to be one of duality in the sense that wave and particle are two equally real, but conceptually exclusive, aspects of the same object. He rejects Bohr's idea that wave and particle are complementary.[93] Several points should be clarified here: (1) As we have already noted, this is technically a misuse of the term "duality" since there is only one object, not two.[94] Undoubtedly, Born uses the term in deference to the popularity of the phrase "wave-particle duality".[95] (2) Born treats the wave and particle aspects as conceptually exclusive in the sense that only one of these interpretations can be used at a time.[96] For instance, the accumulation of a diffraction pattern can be viewed either in terms of the overall pattern (represented by the wave-function) involving a large number of spots (an ensemble of particle-systems),[97] or it can be viewed in terms of the individual impacts (individual particle-events), but these two views cannot be held at the same time. Nonetheless, the two aspects do exist at the same time so they are not mutually exclusive in reality.[98] In fact, both aspects must be considered together for a complete understanding of a given phenomenon.[99]

Hence, Born's wave-particle "duality" differs from Bohr's wave-particle complementarity in that it violates the conditions of individual completeness and mutual exclusiveness. It is rather like the relationship between the whole and the parts in Polanyi's philosophy or in Gestalt psychology.[100] For Born, wave and particle represent two dimensions or projections of reality rather than two modes of existence. We have termed this relation one of orthogonality or modality.[101] (3) However, Born also maintains that the wave and particle pictures are not strictly orthogonal since they are connected by the statistical interpretation of the wave-function.[102] Moreover, they are mathematically represented by the Schrödinger and Heisenberg formalisms, respectively, so one can transform from one to the other mathematically.[103] The same holds for the field and particle pictures in quantum field theory.[104] Hence the two pictures are mathematically equivalent even though they are conceptually exclusive.[105]

At times, Born even spoke of the possibility of eliminating particles[106] or else eliminating waves[107] altogether! In this respect, he suggests that their relationship may be one of equivalence or supplementarity. To summarize: Born regarded the relationship between wave and particle to be one of "duality" rather than complementarity; however, what he meant by duality was really orthogonality, though sometimes he modified it to supplementarity. Moreover, what he meant by "wave" and "particle" was what we have called wave and particle pictures rather than wave and particle modes.[108]

(4) Born regarded the wave and particle aspects to

be equally real because both are invariants of observation. Particles are invariants because they always have the same rest mass, charge and spin.[109] The wave-functions are more abstract since they exist in a multi-dimensional configuration space, but they are just as real because they determine the probabilities for the particle-events and these probabilities are unchanged from one event to another for a given experimental arrangement.[110] As we have noted before, this identification of objective reality with invariance leads to a position of subjective idealism,[111] though this was certainly not Born's intention. In fact, he intended it to counteract charges of subjectivity in quantum mechanics.[112]
<u>Complementarity</u>: In contrast to the invariant properties of waves and particles there are also relative attributes like position and momentum which are complementary to each other, according to Born.[113] These attributes are not inherent in the object; they result from the relation between the object and the experimental arrangement as a whole, and they are only statistically determined by the wave-function and are subject to the uncertainty principle.[114] Born compares them to the different projections of a solid onto perpendicular planes. The apparent shape of the solid changes while the actual shape remains unchanged. We can only view one projection at a time, but from a comparison of the different projections we can reconstruct the invariant shape and know that the solid is objectively real (again equating invariance with reality).[115] For elementary particles, of course, the invariant features are not shape but rest mass, charge and spin.[116] However, several difficulties arise with this

analogy of Born's: (1) He uses the word "complementarity" to refer to position and momentum and also to the mutually exclusive conditions under which they are measured.[117] This usage is closer to Pauli than to Bohr. Moreover, in spite of Bohr's objections, Born states that complementary appearances are due to the disturbing effect of the process of observation.[118] (2) Born is correct in saying that conjugate properties are relational and not inherent, but he wrongly suggests that they are not <u>bona fide</u> attributes of the object. Certainly anger and love are properly regarded as states of the mind even though they are relationally defined. This difficulty goes back to Born's identification of invariance with reality.

(3) Finally, the analogy to the projections of a solid is a hopeless muddle. As a model of complementarity it violates the conditions of completeness, coexhaustiveness (there are generally more than two projections), alternation, coinherence, exclusiveness, reciprocity, emergence and pointing. We have seen that it is not just the apparent shape of the phase-cell, but its actual shape which changes as the object alternates from one mode to the other (oscillating phase-cell model).[119] The invariant here should be the volume rather than the shape, so the change is not just a change of appearance; it is a change in the object itself. In fact, the projections of a solid onto different planes never change at all unless the object rotates, but such a "rotating phase-cell model" would not satisfy the Heisenberg uncertainty principle in all instances,[120] so it would not preserve the one invariant that does exist. In short, Born has replaced

complementarity with the idea of orthogonality or modality. His "projections" are simply the orthogonal dimensions of an invariant reality and do not satisfy the conditions for complementarity, as Bohr understood the term.[121]

4.6 Pascual Jordan:

Pascual Jordan must be one of the most prolific and imaginative scientists of our century. Besides being one of the founders of quantum mechanics and quantum field theory, he has made contributions to cosmology, geophysics, biology, psychology, and even religious questions.[122] Strangely enough, Jordan claims to be a thorough-going positivist;[123] that is, he holds that the aim of science is to collect and organize sense data and not to seek an underlying essence of things.[124] He embarrassed many of his colleagues (especially his mentor, Max Born) by claiming that all quantum physicists, and especially complementarists, must be positivists,[125] thus providing grist for the mills of many critics.[126] He must have horrified Bohr with his repeated statements that all observations are an "intrusion" (Eingriff) into nature[127] and that all phenomena appear under the "coercion" (Zwang) of experimental arrangements so that an objective description is impossible.[128] However, he partially redeemed himself by saying that the features of complementarity and uncertainty are grounded in nature itself and are not simply due to the limits of knowledge or of measurement.[129] Like so many physicists, he did not really have a consistent philosophical outlook, and he should not be judged on the basis of occasional unguarded declarations.

In an important paper on the quantum theory of measurement Jordan rejected the subjectivist interpretation of von Neumann[130] and maintained that entropy (the measure of randomness) is an objective property of systems which is independent of the knowledge (or ignorance) of the observer and hence is the same for all observers. He concluded that the thermodynamic description (in terms of temperature and entropy) of an atom is complementary to its space-time description in a way that is independent of the existence of wave-particle complementarity.[131] What Jordan has in mind here is not the same thermodynamic complementarity that we discussed in chapter 3.1, but a thermodynamical interpretation of von Neumann's concept of a "pure state" or "pure case", i.e. the representation of the state of a system by a single wave-function which evolves continuously and causally in accordance with Schrödinger's equation. The act of measurement transforms a pure case into a "mixed state" or "mixture" of the Eigenfunctions of the mathematical operator representing the measurement.[132] In an ensemble of atomic systems all of these Eigenfunctions will be found but for a single atom only one can be realized at a time, and this selection is purely statistical in contrast to the causal evolution of the pure case, itself.[133] So the transition from a pure case to a mixture is sudden and acausal, like the quantum-jump of an atom.[134] Therefore, Jordan argued, there is a relationship of complementarity between a pure case and a mixture, or between evolution by Schrödinger's equation and quantum-jumps, or between causality and space-time description.[135] In fact, if one substitutes "wave-mode" for "pure case" and "particle-mode" for "quantum-jump", then one has the relationship of complementarity as Bohr saw it. The only difference is that von Neumann and Jordan use abstract, mathematical concepts, whereas Bohr uses concrete, physical ones.[136]

Jordan's principal applications of complementarity have been in the fields of biology and psychology, and here, he tells us, he owes his basic insights to his correspondence and conversations with Niels Bohr.[137] Jordan's principal contribution to biology is his "amplifier theory of organisms" (Verstärkertheorie der Organismen), in which the effects of microscopic fluctuations are amplified into the characteristically unique features of living organisms.[138] Some examples are the role of mutations in heredity and the sensitivity of the eye to individual photons.[139] It is due to this "sensitivity" (Empfindlichkeit) of the organism that it is impossible to determine the state of all the atoms in the organism without destroying it, hence the feature of complementarity first suggested by Bohr.[140] Of course, this "amplifier theory" is not in itself sufficient to guarantee the irreducibility of life phenomena since only a very few atoms would have to be sampled to determine the microstate of a relatively homogenous body.[141] In the case of an organism, however, there is strong inhomogeneity even at the level of the chromosomes, so a mere sampling would not be sufficient.[142] Amplification and inhomogeneity, then, are the two features which distinguish organisms from mechanical or thermodynamic systems and make a physico-chemical explanation of life impossible.[143]

In the area of psychology, Jordan also makes several interesting applications of complementarity. He mentions the impossibility of observing how one goes to sleep,[144] thus illustrating the general principle that A-experienced and A-analyzed are quite different from each other.[145] He also develops Pauli's suggestion that the relationship between the conscious and unconscious minds is one of complementarity,[146] and specially points out Freud's idea that neurotic symptoms can only exist as long as their real significance is not consciously realized.[147] In other words, repression (Verdrängung) in psychoanalysis is the correlate of reciprocity in quantum physics. In a "split-personality", for instance, the dominance of one personality represses the manifestation of the other just as in an electron the appearance of wave properties (well-defined momentum) "suppresses" the appearance of particle properties (well-defined location).[148] In this sense, Jordan says that Freud's concept of repression is the positive side of his idea of the unconscious just as the principle of complementarity is the positive side of the discovery of indeterminism in quantum physics.[149]

The same difficulty arises with this "split-personality" model as with Pauli's complementarity of the conscious and unconscious minds. The usual conception of a dual-personality is that both halves exist at the same time and in mutual opposition.[150] Either they are two different personalities altogether, or else two coexisting projections of a single multi-dimensional personality. If a complementarist model is to be used, then the two "halves" must be seen as wholes, that is, alternate modes of existence for the total personality. However, neither Jordan nor Pauli has worked out a fully complementarist model in this sense.

4.7 Walter M.Elsasser:

Elsasser has certainly gone more deeply into the application of complementarity to thermodynamics and biology than anyone else. Like Jordan, he claims to be a strict positivist, and he also follows the operationalism of Percy Bridgman.[151] In fact, he had Bridgman proofread his first book on biology to make sure that all the concepts used could be operationally defined.[152] The operationalist approach is particularly evident in Elsasser's insistence on dealing with ensembles or classes of equivalent systems and his strict definition of probabilities in terms of statistical frequencies.[153]

Elsasser introduced what he calls the "generalized principle of complementarity" in 1937: "If systems with many degrees of freedom are involved, the possibility of giving a unique quantum-mechanical representation of a system by a pure state and the possibility of leaving it in approximately the conditions under which it appears as a sample of a given collection, will in general exclude each other."[154] At this point Elsasser was thinking primarily in terms of statistical thermodynamics; it was another twenty years before he published his first work on biology. He was undoubtedly familiar with Bohr's efforts to apply the principle of complementarity to thermodynamics,[155] but he apparently wanted to replace Bohr's intuitive arguments, based on the classical statistical mechanics of Maxwell, Boltzmann and Gibbs, by a more rigorous argument, based on the quantum theory of measurement.[156]

He argued that in order to treat a quantum-mechanical system as a "pure case" it is necessary to determine its wave function, i.e. to determine the location and shape of its representative cell in phase space (subject to the limitations of the uncertainty principle).[157] This can be done (in principle) for a simple system consisting of a very few atoms. But for systems with large numbers of atoms and hence large numbers of degrees of freedom (dimensions in phase space) the effort to determine simultaneously the approximate positions of all the atoms would require bombardment with a large number of high-energy x-rays (wavelength about one Angstrom unit), which would greatly increase the average momentum of the atoms and cause the system to burst into many parts. In this case the system could not be treated as a member of a statistical ensemble of equivalent systems since its behavior would be radically different from that of any other system on which the same measurement had been performed. Therefore a system of many atoms can be represented by a pure state in quantum mechanics only by disrupting the system itself and destroying its equivalence to other similarly prepared systems.

The alternative, of course, is to isolate the system from external influence and treat it as a <u>bona fide</u> member of a statistical ensemble which is represented mathematically by a statistical matrix of wave-functions. In this case the wave-function is only statistically determined,[158] and the system cannot be represented by a pure state. Elsasser's conclusion is that "the use of an ensemble for describing and especially for predicting the average behavior of a collection of systems as found in nature and the precise knowledge of the state of the individual samples exclude each other."[159] Hence, there is a relationship of complementarity between the quantum-mechanical description of a system by means of a pure state and the statistical-mechanical description by means of a statistical matrix. This is Elsasser's "generalized principle of complementarity".

By way of critique we should note that Elsasser has concentrated on the possibilities of observation and measurement rather than those of definition, reflecting his general operationalist philosophy.[160] Given the framework of the quantum theory of measurement he might just as well have regarded the limitations he discusses as matters of definition. This would certainly have made his arguments more consistent with Bohr's approach and more acceptable to a non-operationalist audience, as well. It is significant, in this respect, that Elsasser regards the necessity of using statistics in thermodynamics to depend on the validity of quantum theory. Hence his "generalized principle of complementarity" is simply the wider application of quantum-mechanical complementarity to systems with large numbers of atoms, whereas Bohr regarded each application of complementarity to be a separate issue.[161] Elsasser insists that in classical thermodynamics the use of statistics is only a labor-saving device since the microstate of the system could always be determined (in principle) by measurements which do not essentially disturb the system.[162] Thus he sets aside Bohr's arguments based on the possibilities of definition in terms of the classical theories[163] and considers only the possibilities of classical measurements. Ultimately, of course, the two approaches should give the same results,[164] but philosophically there is a world of difference between them.[165]

Elsasser's interest in biology was first aroused by Bohr's paper on "Light and Life" published in 1933,[166] and his work in this field, he states, is basically a logical extension of Bohr's.[167] Specifically, he attributes his "generalized principle" to the insights of Bohr and regards this as one of the three basic principles that lie at the foundation of all biology. The other two principles are the principle of finite classes (or inhomogeneous classes) and the principle of supra-mechanical "biotonic" stability or the "non-storage of information".[168] We shall examine each of these in turn.

(1) We have already reviewed Elsasser's application of generalized complementarity to thermodynamic systems. The application to biological systems is basically the same: there are two alternate modes of existence which Elsasser calls <u>mechanical</u> (physico-chemical or quantum-mechanical or molecular) and <u>organismic</u> <u>or</u> <u>biotonic</u>,[169] and the scientist can choose to study either one or the other, but the two are mutually exclusive. Any attempt to determine the mechanical microstate (i.e. the wave-function) would disrupt the biotonic regularities and kill the organism. Conversely, the decision to study the biotonic regularities, themselves,

restricts the available information about the micro-variables to statistical inferences based on the observed macro-variables (e.g. weight, pulse-rate, etc.).[170] This, Elsasser argues, is the essence of Bohr's considerations, but it does not go far enough because (a) it applies equally well to thermodynamic systems and so does not take into account the distinctive qualities of living organisms themselves - this leads to Elsasser's principle of biotonic stability[171] - and (b) Bohr has considered only the study of individuals and has not considered the possibilities available from the study of ensembles or classes of individuals - this leads to the principle of finite classes.[172]

(2) In thermodynamics, as we have seen, one can statistically determine the microstate of a complex system by treating it as a member of an <u>homogeneous class</u>, i.e. a large ensemble of systems which are identically prepared and therefore all have the <u>same macrostate</u>. If it is impossible to control the preparation of the systems one starts with a naturally-occurring inhomogeneous class and selects a sub-class that is reasonably homogeneous. Obviously, the greater the inhomogeneity of the natural class, the greater its size must be in order for it to contain homogeneous subclasses. In the extreme case of the radically inhomogeneous class of living organisms, the size of the natural class must be immense if the microstate of any given organism is to be statistically determined. Elsasser then shows that the number of organisms in the universe is not large enough to make this possible. The argument proceeds as follows: clearly the number of organisms must be much larger than the possible

number of macrostates in order to ensure the existence of a substantial subclass of organisms with the same macrostate. But even that is not enough: in order to have a good set of statistics the number of organisms in this subclass must be much larger than the number of equivalent microstates, i.e. the number of microstates consistent with the given macrostate. Hence the number of naturally-occurring organisms must be much, much larger than the number of microstates of an homogenous subclass. But a rough estimate shows that even if the earth were literally covered with living cells and there were 10^{20} other planets in the universe covered with living cells and every microsecond of each cell's existence were counted as a separate system-event and if life had existed for thirty billion years (a generous estimate of the age of the universe), the total number of system-events would still be immensely smaller than the number of equivalent microstates of a single cell![173] Therefore, even if all the cells in the universe were considered to have the same macrostate for all their lives and hence to constitute an homogeneous class, it would be impossible to make any statistical inferences about the microstate of even a single cell. All this is not to mention the practical difficulties involved in obtaining and studying all these cells or the ethical problems involved in killing them all save one. Elsasser's conclusion is that the irreducible essence of life is seen in the relationship of the individual organism to the class of all organisms. That class is finite and radically inmomogeneous, therefore life cannot be reduced to the terms of physics and chemistry.[174]

Comments: (a) In spite of Elsasser's claim to have developed this idea himself, we should remember that Bohr also pointed out the impossibility of defining the atomic state of an organism due to its fundamental complexity and inhomogeneity.[175] (b) There is something rather arbitrary about basing an argument concerning the nature of life on the number of planets in the universe and the length of time that life has existed on them. It is possible that a universe such as ours could not conceivably exist in sizes large enough to reverse Elsasser's inequality.[176] Perhaps a universe of such proportions would be too massive to allow sufficient expansion (against gravitation) and cooling to provide conditions for life as we know it. But what about the age of life in the universe? Perhaps this is only a few billion years,[177] but could the potential future of life be limited simply because it cannot be explained in terms of physics and chemistry?[178] Or could it be that, if life is to continue indefinitely, then it must become ever more complex so that it never reaches the stage where it reverses Elsasser's inequality and automatically becomes reducible to the laws of quantum mechanics?[179] I don't think Elsasser has thought through the implications of his argument beyond the limited considerations of the use of statistics. As far as he is concerned the construction of an homogeneous class of organisms is impossible in practice, therefore it is meaningless to speculate about the possible application of quantum-mechanics to living beings.[180]

(c) However, there is another possible objection which Elsasser does consider: the same quantitative estimates can be done for inorganic systems like crystals, and the result is the same inequality so nothing has been proved. To answer this objection Elsasser drops the consideration of classes and returns to the basic inhomogeneity of individuals (which was Bohr's original point) and the importance of feedback mechanisms. The macrostate of a crystal or a dust particle is quite insensitive to its microstructure, and the moderate inhomogeneity at the atomic level can be averaged over without significant loss of information.[181] Even major inhomogeneities are simply treated as "impurities" and usually neglected without loss.[182] Just the opposite is true for an organism, however, since it is strongly inhomogeneous at the molecular level and very sensitive to even the slightest changes at that level due to the presence of feedback mechanisms or "ergodizers" (cf. Bohr and Jordan on amplification effects).[183]

Conclusion: Elsasser's principle of finite classes is faulty in several respects, and when suitably modified it amounts to little more than the principles of Bohr and Jordan based on the complexity and inhomogeneity of organisms at the atomic level and the importance of amplification effects. Elsasser probably would not have placed so much emphasis on a consideration of classes in the first place had it not been for his commitment to operationalism. In fact, there are points where he drops his guard and speaks simply of the uniqueness of individuals! No two sheep or blades of grass are exactly alike.[184] It may be that in the back of his mind he is thinking of the qualitative individuality of organisms which we know intuitively but can never explain in quantitative terms.[185]

(3) Elsasser's principle of supra-mechanical stability is similar to his principle of finite classes except that it applies to the individual itself, rather than the relationship of the individual to a class. Since the total number of system-events for the whole universe is immensely smaller than the number of equivalent microstates for a single cell, it follows that the total number of system-events for any single organism must be immensely smaller than the number of its equivalent microstates. Therefore only an immensely small percentage of the microstates corresponding to any given macrostate will be realized during the organism's lifetime, and all macrostates will be equally improbable.[186] This accounts for the variability and flexibility of organisms, but it makes any quantum-mechanical explanation of their remarkable stability completely impossible.[187] The efficient storage of information by an organism is a biotonic feature that cannot be explained in (quantum) mechanical terms.[188] From the viewpoint of complementarity (in Bohr's sense) this stability simply illustrates the feature of emergence like the emergence of stability in atoms which cannot be explained in (classical) mechanical terms.[189] Elsasser does not include this feature in his definition of "generalized complementarity" because he virtually equates complementarity with the uncertainty principle.[190]

In conclusion, Elsasser's principles of generalized complementarity and biotonic stability are together equivalent to Bohr's principle of complementarity. Elsasser's original contribution is the principle of finite classes, but this is open to serious objections.

4.8 Philipp Frank:

We turn now to two physicists who were directly associated with the Vienna Circle and represent logical positivism in its purest form. Their interpretations of complementarity are unique and serve to illuminate the differences between Bohr's philosophy and positivism.[191]

Philipp Frank considers the principal contribution of Bohr's philosophy to be his attention to the conditions for the application of everyday concepts.[192] The significance of this attention is for Frank, however, the attainment of a coherent logical syntax rather than unambiguous communication.[193] The significance of complementarity is that the whole of everyday language is broken up into complementary sublanguages suitable for different experimental situations.[194] So as long as one restricts complementary analysis to the use of language, Bohr's philosophy is consistent with positivism, but as soon as complementary modes are attributed to objects one has drifted into metaphysics and mysticism.[195] In reality, there is neither wave nor particle, but only measurable quantities like momentum and position subject to the uncertainty principle.[196] In spite of all this, Frank claims that there is no difference between Bohr's view and his own on the meaning of complementarity in physics; but there is a real difference, he admits, with regard to the application of complementarity to biology and psychology.[197] In fact, Frank virtually rejects these applications.

In biology, Frank argues, a complementarist approach is "possible", "certainly tenable", "perhaps even desirable", but given the present state of biological knowledge it is not a necessary, but only a convenient approach.[198] The parallel to atomic physics breaks down because in atomic physics complementarity is demanded by the evidence (e.g. the observed stability of atoms), and this evidence cannot be explained in terms of the laws of classical physics. So far, however, there is no empirical evidence for a contradiction between the properties of living organisms and the laws of quantum physics.[199] One wonders whether Frank would have accepted Elsasser's arguments here if they had been available to him at the time. The only evidence for complementarity that he cites is the impossibility of observing the exact atomic configuration of an organism without causing death.[200] The possibilities of definition, which Bohr stressed, are completely ignored.[201] However, Frank was never really open to Bohr's arguments in the first place. He even states at one point that complementarity can never serve as a scientific argument in favor of an organismic conception of nature since it is purely negative and can only lead to the replacement of one kind of physical description (e.g. classical mechanics) by another (quantum mechanics).[202] Therefore, even if complementarity could be conclusively demonstrated in biology it would only transform biology into another branch of physics! Ultimately, nothing is beyond the range of physics and chemistry because the only legitimate data are physical data.[203] This kind of reductionism is completely opposed to the intent of Bohr's philosophy, and it would have been better for Frank to say so openly rather than try to harmonize the two at Bohr's expense.

In the same reductionist vein, Frank tries to use complementarity in psychology as an argument in favor of behaviorism. Since one cannot experience an emotion and analyze it at the same time, a causal account of mental life (the only kind acceptable to Frank) cannot be based on introspection as Comte pointed out over a century ago. Therefore, a scientific account must be based exclusively on the behavior of others with no appeal to one's self-understanding. Once introspection is eliminated in this manner, psychology becomes a branch of biology, and all complementarist considerations disappear![204] Of course, our language still contains statements about personal "freedom", and such statements will always be complementary to statements about causal determination, but in this sense "freedom" means simply the absence of compulsion ("liberty of spontaneity") and has nothing to do with metaphysical "freedom of the will".[205] In fact, such a transition into metaphysics is ruled out, according to Frank, by Bohr's own restriction to classical language and logic. The terms of a complementarity relationship must be taken from everyday life, not from metaphysics.[206] Clearly he is wrong here for even the terminology of physics is derived from ordinary language via metaphysics.[207] Therefore, metaphysical terms like "free-will" and "mind" cannot be ruled out by positivist criteria.

Frank rejects an argument made by Sommerfeld that mind must be complementary to body because it cannot be localized within the body.[208] The same thing could be said, he argues, of the function of a machine.[209] Of course, when Frank wrote this (1938) machines were still regarded as being purely "mechanical"; the idea of function was regarded to be an epiphenomenon like mental life itself.[210] In retrospect, however, we can see that Frank's analogy is a good one and that machines (in fact all human artifacts) participate in the same complementarity as their creators.[211]

4.9 Hans Reichenbach:

Reichenbach was less critical and more creative than Frank with regards to Bohr's ideas. In fact, he offered his own alternative to complementarity which he called the "principle of anomaly".[212] Briefly stated, it asserts that no uniform causal account of "interphenomena" is possible on the atomic scale.[213] For instance, single-slit diffraction can be understood solely in terms of a wave-picture only if the wave is allowed to collapse instantaneously and acausally when it impinges upon a screen. On the other hand, it is possible to interpret this experiment solely in terms of the scattering of classical particles by the slit without such a "causal anomaly". Just the opposite is true, however, for double-slit diffraction (Young's experiment). Since a particle can only pass through one slit at a time, there must be some action at a distance of the second slit on the particle which makes the diffraction pattern different from that of the single-slit experiment. In this case, the causal anomaly can be avoided only if a modified wave-picture is used. The point is that neither wave nor particle picture can account for both experiments without causal anomalies.[214]

Reichenbach discusses two possible solutions for this dilemma, which he calls "restrictive interpretations" because they avoid the anomalies by suitable restrictions on the discussion of interphenomena. The first is a restriction of meaning. It simply rules out all statements about interphenomena (e.g. about the path of the particle in the double-slit experiment) as meaningless. Reichenbach attributes this version to Bohr and Heisenberg but does not support this allegation with any specific references to their writings.[215] The second interpretation is a restriction of assertability. Rather than ruling out statements about interphenomena as meaningless, it introduces a three-valued logic and treats them as potentially indeterminate. Such statements always occur in pairs, only one of which can be determinate at a time. For instance, the particle approaching the double-slit has a determinate momentum and indeterminate position, but when it finally impinges upon the screen it has a determinate position and indeterminate momentum. In the idiom of complementarity, as we have studied it, the "particle" exists first in the wave-mode and finally in the particle-mode.[216] Hence Reichenbach's "interpretation of restrictive assertability" is practically equivalent to Bohr's principle of complementarity. In fact, his "three-valued logic" is identical to the multi-valued "logic of complementarity" developed by von Weizsäcker.[217]

The main weakness in Reichenbach's principle of anomaly is his separate treatment of phenomena and interphenomena. He admits that no sharp distinction can really be drawn between the two since both involve inference and interpretation on the part of the scientist, only in different degrees.[218] Furthermore, Reichenbach recognizes that the phenomena themselves appear to be either corpuscular (when position is measured) or wave-like (when momentum or wave-length is measured) even though these phenomena could be interpreted in terms of either of the two pictures if necessary.[219] Therefore, a more unified treatment could be achieved by extending the principle of anomaly to include both phenomena and interphenomena. The result would then be entirely equivalent with Bohr's principle of complementarity.

4.10 John A. Wheeler and Richard P. Feynman:

Two of the most imaginative physicists of the post-war period have been John Archibald Wheeler and Richard Phillips Feynman. Some of their ideas are rather speculative, but they ought to be studied as possible developments for the principle of complementarity in the future. There are two separate theories to be considered, the "direct particle interaction" formulation of electrodynamics developed by Wheeler and Feynman and the "relative-state" formulation of quantum mechanics developed by Everett and Wheeler.

The "direct particle interaction" formulation of electrodynamics was developed in the 1940's as an alternative to the usual conception of indirect transaction by means of electromagnetic waves.[220] In the usual conception a source is thought to radiate a wave which travels outward until it happens to be absorbed by another particle. This <u>trans-action</u> is one-way, from the source to the absorber, and the initial process of radiation is entirely independent of the (presence or absence of) the absorber. Hence transaction by intermediary fields is a form of action by contact, as Einstein called it, in contrast to the Newtonian action at a distance.[221] The Wheeler-Feynman conception on the other hand, is of a direct, two-way <u>inter</u>action between the source and the absorber. The initial radiation by the source is actually stimulated by the "advanced-potential" (travelling backwards in time) of the absorber, which is in turn produced by the "retarded potential" (travelling forewards in time) of the radiating source.[222] The circular relationship between source and absorber means that the source could not possibly radiate unless there were another particle somewhere in the universe to absorb its radiation. Hence, source and absorber, past and future, are interdependent.[223]

Because the interaction is two-way and symmetry is maintained between past and future, Wheeler and Feynman regard this "direct particle interaction" to be a modern version of Newtonian action at a distance. Furthermore, they regard their treatment, which emphasizes the interacting <u>particles</u>, as being equivalent but complementary to the usual treatment, which emphasizes the intermediary <u>fields</u>.[224] The choice between the two treatments is strictly a matter of convenience: when dealing with actual electromagnetic radiation (real quanta) the field-picture is more suitable, but when dealing with electromagnetic fields (virtual quanta) the direct particle interaction approach is more convenient since it automatically avoids the infinite "self-energy" terms that appear in the field theory.[225] Still the two formulations must be equivalent because one can transform from a picture involving the annihilation and subsequent recreation of an antiparticle pair (involving the mediation of a real photon) to a picture involving the direct interaction of a pair of identical particles (involving the exchange of a virtual photon) by a simple "crossing" transformation.[226] In other words, Feynman and Wheeler have presented us with a new form of supplementarity, not complementarity in the proper sense.[227]

We turn now to the "relative-state" formulation of Everett and Wheeler.[228] This theory is essentially the logical development of von Neumann's quantum theory of measurement.[229] It is well-known that von Neumann's approach leads to an infinite regress:[230] A quantum-mechanical system cannot have a unique state unless it is observed by an outside agent (the pure state is then transformed into a mixture).[231] But the process of observation itself can be analyzed quantum-mechanically (according to von Neumann) so the observer-observed system as a whole still does not have a unique state unless it in turn is observed by a second agent, and so forth.[232] The Everett-Wheeler theory simply defines the state of the observer in relation to the state of the observed object.[233] Since the object has no unique state, then neither does the observer, and the act of measurement, rather than transforming the object into a unique state, actually transforms the observer into an infinite superposition of states! The observer branches into an infinity of "observers" each with a different state corresponding to the possible states of the observed object.[234] And the second observer likewise branches into an infinite number of "observers" with different states corresponding to the possible states of the first observer and so on. The result is a complete branching of the universe into an infinite number of new "universes" and a complete rebranching again and again as these interactions go on. The beauty of it is that there is no discontinuity or acausality since all possible developments are realized at once.[235] The statistical laws of quantum mechanics completely determine the numbers of universes that follow any given course of events. Moreover, there is no appeal to classical physics, and the correspondence principle is entirely eliminated.[236] Of course, there can be no communication between the different branches so our subjective feeling of uniqueness is not violated; in fact, there is no way at all to either verify or falsify the existence of other branches besides our own universe.[237] This theory does not alter the laws of quantum mechanics in any way; it simply reinterprets them so that they are conceptually self-contained and hence logically simpler than in the orthodox representation.[238] Therefore, the "relative-state" formulation can only be judged on basically aesthetic grounds.

Although the correspondence principle is eliminated in the "relative-state" formulation, the principle of complementarity apparently is not. Wheeler is a staunch supporter of complementarity,[239] and in the note he appended to Everett's first publication[240] he argued that complementarity is maintained between the memory states for successive measurements of conjugate variables.[241] If an electron is measured first with respect to its position and then with respect to its momentum and then again with respect to its position, the observer's memories of the two position measurements will be correlated statistically in accordance with the uncertainty principle. So the Everett-Wheeler formulation eliminates indeterminacy, but retains the features of irreversibility and real becoming; it dispenses with the correspondence principle, but retains the basic features of complementarity. In Bohr's philosophy these ideas are all interdependent; Everett and Wheeler have shown us that they can be separated if one is willing to admit an infinite plurality of universes.

4.11 Adolf Meyer-Abich:

The only biologist so far to make use of complementarity is Adolf Meyer-Abich.[242] In a brilliant paper on theoretical biology he discusses three distinct but related applications of complementarity to his field of study. First there is the relationship of form and function or of homology and analogy, as represented by the studies of morphology and physiology, respectively.[243] Meyer-Abich points out that whereas the characteristic feature of 18th and 19th century biology was the attempt to subordinate one to the other (the "problem of domination"), modern biology, with the development of physiological anatomy and anatomical physiology, has come to regard the two as being complementary. Morphology and physiology are logically independent and each uses categories which embrace the whole field of biology while at the same time excluding the categories of the other. Yet neither can be reduced to the other, and both are necessary for a full understanding of biology.

Secondly, Meyer-Abich cites the relationship between an "organismic subject" (e.g. cell, organ, organism) as part of its external world or biotic environment and the same organismic subject as the totality of its internal world (Umwelt-Innenwelt Beziehung).[244] When we treat an organism in relation to its biotic environment, we regard it as a functional unit within that environment, and individual organs are all part of the internal world of the organism. However, it is also possible to analyze the organism in terms of its individual organs, i.e. as a composite structure.[245] In this case each organ is part of the external world or environment of every other organ. Moreover, the two approaches are not just alternate viewpoints; they represent alternate modes of the "organismic subject" itself. In fact, there is no direct connection between an internal organ and the external environment of an organism. The environment affects the organism as a whole, in its functional mode, and the individual organs are only affected as the organism reverts to its structural mode.

Note that Meyer-Abich regards the environment of an organism as a higher level of unity because he refers to the biotic or ecological environment, not just the physical environment. In our previous discussion we have only considered external influences on an organism at the atomic level of sense impressions (e.g. light waves, sound waves, etc.).[246] In these instances, the organism receives a stimulus at the atomic level and translates it upwards to higher levels. In Meyer-Abich's model, however, the organism is so well integrated into its biotic environment that it responds to environmental changes as a whole and translates the influence downwards to lower levels.[247] Clearly, both mechanisms are possible, and their occurrence simply depends on the degree of integration or isolation between organsim and environment in each case.

One important aspect of the Umwelt-Innenwelt Beziehung, according to Meyer-Abich is the complementarity between natural selection and ecological adaption, or between the corresponding sciences of genetics and ecology.[248] The old debate over the inheritance of acquired characteristics can only be resolved when it is recognized that these two sciences are based on mutually exclusive postulates and are really complementary in that both together are needed to explain the full range of hereditary and evolutionary phenomena. Modern genetics works only with pure lines of descent for which there is no real adaption, and the only possibility of evolution is through gene mutation and natural selection. Ecological adaption, on the other hand, is directed by final processes of reconstruction. Here Meyer-Abich suggests that ecological adaption may be responsible for the "macroevolution" of the thirty-or-so original "archetypes" of organisms (e.g. vertebrates, arthropods, molluscs, etc.) and that gene mutation and natural selection are largely responsible for the evolution of the subsequent "paratypes". The two complementary mechanisms correspond to teleological or final causes and effective causes, respectively.[249]

It is remarkable how well Meyer-Abich has grasped the intent of Bohr's ideas, especially in view of the fact that he was not trained in physics. The ease with which he adapts the concept of complementarity to biology reminds us of the fact that Bohr's father was a biologist with a keen interest in the vitalist-mechanist debate and Bohr's own thinking was strongly influenced by these considerations.[250]

4.12 Paul Oppenheim et al.:

The most systematic attempt to define complementarity rigorously and apply it to psychology and religion has been made by Paul Oppenheim and his associates.[251] Their basic definition is summed up in the statement: "Complementary phenomena have non-compatible interpretations."[252] This means first of all that complementarity is a relationship between "phenomena" or "phenomenon sentences", i.e. between descriptions or statements about observable events such as the click of a Geiger counter or the stretching of a spring balance.[253] These "phenomena" are therefore macroscopic events which can and must be described solely in terms of classical physics. Their interpretations, on the other hand, will involve statements ("interpretational sentences") about unobservable quantum events in the microscopic world. These events must be described in "quasi-classical" language, i.e. classical language that is used analogically and so undergoes a semantical change when applied to the non-classical world of quantum events.[254] For instance, the click of a Geiger counter can be interpreted as the impact of a particle at that precise instant of time, and the stretching of a spring balance can be interpreted as the change in energy or Doppler-shift of a wave.

Oppenheim et al. call these phenomena "complementary" and their interpretations "non-compatible". By "complementary" they mean that the phenomena (a) occur under mutually exclusive conditions (cf. our condition 8), (b) are caused by the same atomic object (cf. our condition 1), and (c) together exhaust the possible types of phenomena caused by that object (cf. our condition 4).[255] By "non-compatible" they mean that the interpretations utilize concepts like wave and particle which are incompatible but not co-referential (i.e. not applicable to the same object) in classical physics and co-referential but not incompatible in quantum physics since they apply only to complementary phenomena and are therefore never applicable at the same time.[256] All of this is packed into the short definition: "Complementary phenomena have non-compatible interpretations"!

The principal value of this formulation is the clear statement about the semantical change that classical language undergoes when applied to quantum events. As we saw in our discussion of the correspondence principle, this is one of the most difficult and least understood points in Bohr's philosophy. However, Oppenheim's dual treatment of phenomena and interpretations is unnecessary (except from a positivist viewpoint) and unduly restrictive on the use of the word "phenomenon".[257] The three-point definition of complementarity is perfectly correct as far as it goes, but it is somewhat incomplete compared with the complex use of the term in Bohr's writings.

Oppenheim et al. have recently applied their formulation of complementarity to the mind-body problem with rather interesting results.[258] They divide the world of discourse into statements about two groups of "entities" (i.e. things, events, processes, etc.), mental and bodily.

The difference is that <u>mental entities</u> or "experiences" permit privileged access (experience only by the person to whom they are attributed) and are never experienced as having a specific location within the body, whereas <u>bodily entities</u> do not permit privileged access and do have a specific location in the body of the person to whom they are attributed.[259] The authors then make a further distinction on the basis of language usage: Some entities (entities$_1$, whether mental or bodily) are <u>theory-free</u> in the sense that they are only referred to in statements which are free of concepts taken from a particular psychological theory. Others (entities$_2$) are referred to in statements which do use theoretical concepts and so are <u>theory-bound</u>.[260]

The authors then argue that mental entities$_1$ and bodily entities$_1$ are <u>incompatible</u> like waves and particles in classical physics, that is, they can never refer to the same object and therefore cannot be complementary.[261] The example cited is that of fear, a mental entity$_1$, on the one hand, and blushing, a bodily entity$_1$, on the other. Clearly these two are incompatible for a person is not likely to blush when he is afraid! But the example is poorly chosen for one could just as easily take fear and trembling which clearly are not incompatible; in fact, they are practically synonomous.[262] Here the authors' analysis breaks down badly. Turning to entities$_2$ they then argue that mental entities$_2$ and bodily entities$_2$ are not incompatible but <u>non-compatible</u>.[263] For instance, one particular theory correlates the sensation of hunger with a concentration of glucose in the hypothalamus. Both of the terms here are theory-bound since hunger is defined as a psychological state (e.g. by the "cognitive dissonance" theory) rather than as a personal experience. Moreover, the two terms are non-compatible, like wave and particle in quantum physics, because they are defined under mutually exclusive experimental conditions. Hence, mental $entities_2$ and bodily $entities_2$ are complementary.

The only weakness in the analysis of Oppenheim et al., is the artificial distinction between theory-free $entities_1$ and theory-bound $entities_2$. Apparently this was introduced in order to provide the distinction between incompatibility and non-compatibility and thereby establish a parallel to the correspondence principle in physics: wave and particle are incompatible in classical physics ($entities_1$) but non-compatible in quantum physics ($entities_2$) due to the semantical change in the meanings of the classical terms. But as we explained before, the correspondence principle is automatically fulfilled in a complementarist treatment of the mind-body problem, so it does not have to be artificially contrived.[264] The "classical model" in this case could be either psycho-physical parallelism (Bohr's choice)[265] or mind-body dualism. In both cases mental entities and physical entities are clearly incompatible since they cannot be co-referential, but in the complementarist model they would be defined under mutually exclusive conditions and so would become co-referential and non-compatible. The artificial distinction between $entities_1$ and $entities_2$ is unnecessary as a distinction between "theory-free" and "theory-bound" entities, but it is taken care of by the correspondence principle as a distinction between incompatible and non-compatible entities.

If any general conclusion can be drawn from our study of Bohr's "allies", it is surely that the idea of a monolithic "Copenhagen interpretation" of quantum mechanics is purely a fantasy, at least with regards to complementarity.[266] Every physicist we have studied has an interpretation of his own, and each of these deserves to be studied, appreciated and criticized in its own right. In the following chapter we shall be looking at complementarity from the viewpoint of Bohr's critics. Since much of the criticism is in fact directed at interpretations other than Bohr's own, we should keep these differences in mind.

Footnotes: Chapter 4.

1. On Rosenfeld's collaboration with Bohr see L.Rosenfeld, Niels Bohr: An Essay, and "Niels Bohr in the Thirties".

2. Rosenfeld's most important essays on complementarity are: "Strife About Complementarity", Science Progress 41, 1953, pp.393-410, "L'Évidence de la Complémentarité" in A.George, ed., Louis de Broglie, Physicien et Penseur, Paris, 1953, pp.43-65, "Foundations of Quantum Theory and Complementarity", Nature 190, 1961, pp.384-388, and "Niels Bohr's Contribution to Epistemology", Physics Today 16 (No.10), 1963, pp.47-54.

3. "Niels Bohr's Contribution to Epistemology", p.52.

4. "Strife About Complementarity", p.396, and "Foundations, etc.", p.385.

5. "Complementarity and Statistics", Det Kongelige Norske Videnskabers Selskabs Forhandlinger 31 (No.10), 1958, p.2, "Foundations, etc.", p.384, and "Complementarity", ICSU Review 4, 1962, p.42; cf. ch.2.5 above.

6. "Strife About Complementarity", p.393.

7. Significantly, Rosenfeld introduces his eulogy on Bohr by singing the praises of Hegelian and Marxist dialectics: "Niels Bohr's Contribution to Epistemology", p.47. However, he rejects the mechanistic materialism of Lenin: "Strife About Complementarity", p.401 fn. For an orthodox materialist interpretation of Bohr, see W.A. Fock, "Über die Interpretation der Quantenmechanik", in Philosophische Probleme der Modernen Naturwissenschaft, Berlin, 1962, pp.189-212.

8. "Strife About Complementarity", pp.394,397, "L'Évidence de la Complémentarité", p.51.

9. See esp. Rosenfeld's criticisms of Heisenberg: "Strife About Complementarity", p.401, and "L'Évidence de la Complémentarité", p.63.

10. "Strife About Complementarity", p.397, and "L'Évidence de la Complémentarité", pp.48-49.

11. "Strife About Complementarity", pp.397-398.

12. Compare Bohr's position; ch.1.3 above.

13. "Foundations, etc.", p.388, and "Complementarity", p.46.

14. "The Measuring Process in Quantum Mechanics", pp.224-225.

15. In early articles Rosenfeld stated that our ignorance

of the initial conditions is necessary for the definition of the thermodynamic state of a system, a view similar to Polanyi's: "Strife About Complementarity", p.397, and "L'Évidence de la Complémentarité", p.49; cf. ch.3, fn.18 above. Later he began to emphasize the role of the experimental conditions in defining the nature of the phenomena as Bohr had from the start; "On the Foundations of Statistical Thermodynamics", Acta Physica Polonica 14, 1955, pp.9,37, and "Questions of Irreversibility and Ergodicity", p.3.

16. "Foundations, etc.", p.387, and "Complementarity", p.45.

17. "Foundations, etc.", pp.387f, and "Complementarity", p.45; cf. "Niels Bohr in the Thirties", pp.132-133.

18. See Rosenfeld's comments in M.Marois, ed., Theoretical Physics and Biology, Amsterdam, 1969, pp.82-83.

19. See p.94 above.

20. See ch.3, fn.48 above.

21. "Strife About Complementarity", p.398, "L'Évidence de la Complémentarité", p.49, and "Foundations, etc.", p.387.

22. "Foundations, etc.", pp.387-388.

23. cf. above, p.95.

24. W.Heisenberg, Physics and Beyond.

25. "Niels Bohr in the Thirties", pp.118-119,126-127.

26, Pauli's most important paper on complementarity is "Die Philosophische Bedeutung der Idee der Komplementarität", Experimentia 6, 1950, pp.72-75. This together with other philosophical papers is reprinted in Aufsätze und Vorträge über Physik und Erkenntnistheorie, Braunschweig, 1961. See also "Die allgemeinen Prinzipien der Wellenmechanik", in S.Flügge, ed., Handbuch der Physik, Band 5, Teil 1, Berlin, 1958, p.7, and "The Influence of Archetypal Ideas on the Scientific Theories of Kepler", in C.J.Jung and W.Pauli, The Interpretation of Nature and the Psyche, London, 1955, pp.205-216.

27. "Die allgemeinen Prinzipien der Wellenmechanik", p.7, and Aufsätze und Vorträge, pp.14,72,98.

28. See ch.1, fn.127, above.

29. "Die allgemeinen Prinzipien der Wellenmechanik", p.7; cf. above, ch.2, fn.98.

30. Aufsätze und Vorträge, p.21.

31. ibid, p.97.

32. No reason is given: "Die allgemeinen Prinzipien der Wellenmechanik", p.7.

33. Aufsätze und Vorträge, p.16; cf. "Die Wissenschaft und das abendlandische Denken", ibid, pp.102-112.

34. See above, ch.1, fn.129 and ch.3.4.

35. Aufsätze und Vorträge, pp.17, 125; cf. N.Bohr, APHK, p.21; and also Pauli's comment in C.J.Jung, The Structure and Dynamics of the Psyche (Collected Works, Vol.8), London, 1969, p.229, fn.130.

36. Jung attempts to adapt complementarity to his own model in op.cit., pp.231f,287f.

37. See above, ch.3, fn.84.

38. See above, ch.3, fns.23,81.

39. See above, pp.64f.

40. See W.Heisenberg, "50 Jahre Quantentheorie", Naturwis. 38, 1951, p.53, "Erinnerungen an die Zeit der Entwicklung der Quantenmechanik", in M.Fierz and V.F.Weisskopf, eds., Theoretical Physics in the Twentieth Century, New York, 1960, p.46, and Physics and Beyond, pp.76-79.

41. On the differences between their approaches see W.Heisenberg, "Quantum Theory and Its Interpretation", pp.94-108, P.A.Heelen, op.cit., pp.35-36,48, and M.Jammer, The Conceptual Development of Quantum Mechanics, pp.345-347.

42. Heisenberg's principal writings relevant to complementarity are: The Physical Principles of the Quantum Theory, Chicago, 1930, Philosophical Problems of Nuclear Science, New York, 1952, "The Development of the Interpretation of the Quantum Theory", in W.Pauli, ed., Niels Bohr and the Development of Physics, London, 1955, pp.12-29, The Physicist's Conception of Nature, London, 1958, Physics and Philosophy, New York, 1958, "Die Plancksche Entdeckung und die philosophischen Grundfragen der Atomlehre", in Max Planck: Zum Gedanken, Berlin, 1959, pp.43-61, and "Planck's Discovery and the Philosophical Problems of Atomic Physics", in W.Heisenberg et al., On Modern Physics, London, 1961, pp.31-39.

43. See above, ch.2.10.

44. Heisenberg stands more in the tradition of von Neumann in this respect than in that of Bohr; cf. above, ch.2, fn.69.

45. The Physical Principles, etc., p.63, Philosophical Problems, etc., pp.15-16,42, and Physics and Philosophy, p.53. Note: the wave-function in configuration space can also be treated as a state-vector in Hilbert space, see J.von Neumann, op.cit.

46. _Philosophical Problems, etc._, pp.16,55, "The Development of the Interpretation of Quantum Theory", pp.26-27, _Physics and Philosophy_, p.180.

47. "The Development of the Interpretation of Quantum Theory", pp.12,-13,27, _Physics and Philosophy_, pp.41,53,147-148, 160,180, "Die Plancksche Entdeckung, etc.", p.50, and "Planck's Discovery, etc.", p.9.

48. _Philosophical Problems, etc._, p.17, "The Development of the Interpretation of Quantum Theory", p.27, _The Physicist's Conception of Nature_, p.15, _Physics and Philosophy_, pp.53-54. Hence Heisenberg's famous statement that science deals not with nature but with man's knowledge of nature: "50 Jahre Quantentheorie", p.53, _The Physicist's Conception of Nature_, pp.15,24,25,28-29, and "Planck's Discovery, etc.", pp.12-13.

49. _Philosophical Problems, etc._, pp.16,42,55,82,97, "The Development of the Interpretation of Quantum Theory", pp.22,26-27, _The Physicist's Conception of Nature_, p.29, _Physics and Philosophy_, pp.52,54-55; cf. Bohr's warning against the use of such language, ch.1., fn.127, above.

50. _Philosophical Problems, etc._, pp.15-16, "The Development of the Interpretation of Quantum Theory", pp.22,27, _Physics and Philosophy_, pp.49-50; cf. N.R.Hanson, _op.cit._, pp.82-84. A curious reversal occurs here. For Bohr, the basic complementarity is between application and analysis, hence the wave-mode represents the classical description, i.e. the application of the classical conservation laws and the principle of causality which cannot be analyzed in terms of space-time pictures of the constituent particles. But, for Heisenberg, the basic complementarity is between a classical description in terms of space-time events and a quantum-mechanical description in terms of the wave-function and Schrödinger's equation. For Heisenberg, therefore, causality holds in the quantum-mechanical description (wave-function), whereas for Bohr it holds in the classical description (wave-mode). One reason for this difference is that for Bohr a "wave" is basically a physical model taken from classical physics, whereas for Heisenberg a "wave" is an abstract, mathematical concept in the formalism of quantum mechanics. Another reason is that Heisenberg may have misunderstood Bohr's treatment of measuring instruments in which a space-time description of an atomic object (particle-mode) requires stationary instruments and hence a classical space-time description of the instruments, themselves (see ch.1, fn.142 above). Of course, causal description and space-time description are equally classical in themselves, but one or the other is appropriate depending on the nature and function of the system at hand. For stationary measuring instruments a classical space-time description is appropriate, but for stable atoms a classical causal description is appropriate.

51. For Heisenberg's treatment of Kant see Philosophical Problems, etc., p.22, "The Development of the Interpretation of Quantum Theory", p.27, Physics and Philosophy, pp.88-92, "Planck's Discovery, etc.", pp.11-12, Physics and Beyond, pp.117-122; cf. P.A.Heelen, op.cit., pp. xiii-xiv,29,32,48,53-54,140-141,152-153.

52. See above, ch.2.10.

53. See above, ch.1.5, esp.fn.128.

54. See above, ch.1.3.

55. See above, ch.2.11. Compare Karl Barth's treatment of God wholly revealed and wholly concealed: "The relation between the two is not such that in His self-unveiling we have grounds for knowing Him, and in His self-concealment for not knowing Him; in the former case for speaking, in the latter for being silent. We have to know Him integrally and therefore in both these aspects. At every point, therefore, we have to be silent, but we have also to speak." (Church Dogmatics, II,1, ch.29, p.342).

56. See our discussion on "modellists" and "formalists" above, p.17. Heisenberg is clearly a formalist; see The Physical Principles, etc., p.10, Physics and Philosophy, pp.179-181, "Die Plancksche Entdeckung, etc.", p.46. In fact, he believed that all physics will some day be derivable from a single universal equation: Philosophical Problems, etc., pp.118-119, Physics and Philosophy, pp.72-73. In this respect he is closer to Einstein than to Bohr; cf. Physics and Beyond, pp.64-68.

57. "Komplementarität und Logik", Naturwis. 42, 1955, pp. 521-529,545-555 (reprinted in Zum Weltbild der Physik, 8th edn., Stuttgart, 1960, pp.281-329). On von Weizsäcker's relationship with the others, see W.Heisenberg, Physics and Beyond.

58. "Komplementarität und Logik", p.521; cf. K.M.Meyer-Abich, op.cit., pp.155-158.

59. "Komplementarität und Logik", pp.522-523; cf. fn. 29, above.

60. Note: the sense of the term "complementary" here is quite different from the traditional sense in which x is "complementary" to non-x and p is "complementary" to non-p; see e.g. I.M.Copi, Introduction to Logic, New York, 1968, p.136.

61. loc.cit.; cf. above, ch.1, fn. 63.

62. See above, ch.2.5.

63. loc.cit., p.523. On the early development of quantum field theory see G.Wentzel, "Quantum Theory of Fields (Until 1947)", in M.Fierz and V.F.Weisskopf, eds., op. cit., pp.48-77.

64. loc.cit., pp.523-525.

65. cf. K.M.Meyer-Abich, op.cit., pp.185-186. Even then the two are not quite the same. Von Weizsäcker uses the term "circular" because he believes that quantum theory replaces the classical theories as the foundation of physics, whereas Bohr believed that the classical theories would forever remain the foundation and that quantum theory was a superstructure built upon them; cf. ch.1, fn.87 above.

66. loc.cit., pp.525-526.

67. "Bemerkung zum vorstehenden Aufsatz", in Zum Weltbild der Physik, pp.329-331; cf. W.Heisenberg, The Physical Principles of Quantum Theory, pp.58,63-64.

68. cf. fn.51 above. On von Weizsäcker's allegiance to Kant see The World View of Physics, pp.92,115-135, "Komplementarität und Logik", p.525, and papers in T.Bastin, ed., op.cit., pp.28,234.

69. "Komplementarität und Logik", pp.524,526; for Bohr's treatment of the relation between reason and experience see ch.1.4 above.

70. See above, ch.1, fn.152.

71. See above, ch.3, fn.25.

72. cf. our discussion of Polanyi and Bohr, pp.25f above.

73. cf. "Gestaltkreis und Komplementarität", in Zum Weltbild der Physik, pp.332-366, esp. pp.346,347.

74. See ch.3.3 above.

75. Compare Heisenberg's conception of complementarity: above, p.136.

76. For von Weizsäcker's emphasis on the forms of perception, see The World View of Physics, p.57.

77. The World View of Physics, p.102, "Komplementarität und Logik", pp.527-529,545-555, "Die Einheit der Physik", in F.Bopp, ed., op.cit., pp.44-46, and "The Unity of Physics", in T.Bastin, ed., op.cit., pp.236ff. See also G.Birkhoff and J.von Neumann, "The Logic of Quantum Mechanics", Annals of Mathematics 37, 1936, pp.823-843; H.Reichenbach, Philosophic Foundations of Quantum Mechanics, pp.150-160; and P.A.Heelen, "Quantum Logic and Classical Logic", Synthese 21, 1970, pp.2-33, and "Complementarity, Context Dependence and Quantum Logic", Foundations of Physics 1, 1970, pp.95-110.

78. "Komplementarität und Logik". A good summary of this esoteric subject is given by F.Waismann in R.J.Blin-Stoyle et al., Turning Points in Physics, Amsterdam, 1959, pp.149-153. The basic classical concepts are explained in any textbook on logic, e.g. I.M.Copi, op.cit., pp.214,239,255.

79. See L.Rosenfeld, "The Measuring Process in Quantum Mechanics", p.223; cf. above, ch.1, fns.24,26.

80. "Incidentally it would seem that the recourse to three-valued logic, sometimes proposed as a means for dealing with the paradoxical features of quantum theory, is not suited to give a clearer account of the situation, since all well-defined experimental evidence, even if it cannot be analyzed in terms of classical physics, must be expressed in ordinary language making use of common logic." "On the Notions of Causality and Complementarity", p.317; cf. C.F.von Weizsacker, loc.cit., p.527.

81. On the correspondence principle and incommensurability see above, ch.1.4, esp. fn.87.

82. loc.cit., p.428.

83. So Bohr; cf. ch.1.4 above.

84. W.M.Elsasser, "Bemerkungen zur Quantenmechanik freier Elektronon", Naturwis. 13, 1925, p.711.

85. See above, ch.2, fn.101.

86. See above, ch.2, fn.109.

87. For a review of these events see M.Born, "Statistical Interpretation of Quantum Mechanics" (Nobel Prize address, 1954) Science 122, 1955, pp.675-679 (reprinted in Physics in My Generation, pp.177-188).

88. "The fact that I agree with Bohr's fundamental ideas, above all with his 'complementarity principle', is the result of my own thinking, although I am quite aware that mine was only an afterthought, stimulated by Bohr's forethought." Physics and Politics, p.19; cf. "Albert Einstein und das Lichtquantum", p.430, Physics in My Generation, p.153, and The Born-Einstein Letters, pp.154,212.

89. Physics in My Generation, p.153, Physics and Politics, p.21, Natural Philosophy of Cause and Chance, pp.107-108, 232-233.

90. Physics in My Generation, p.105.

91. ibid, p.106, "Bemerkungen zur statistischen Deutung der Quantenmechanik", p.118 fn., Natural Philosophy, etc., p.105.

92. The Restless Universe, London, 1935, p.157, Physics in My Generation, pp.106,129, "Bemerkungen, etc.", p.113, Physics and Politics, p.57 fn.

93. See the last two references in fn.91.

94. Atomic Physics, pp.98-99.

95. See ch.2.1 above.

96. Physics in My Generation, p.52, "Bemerkungen, etc.", pp.114-115, and Atomic Physics, pp.96,103.

97. Born agreed with Einstein that the wave-function only applies to ensembles of systems (The Born-Einstein Letters, pp.186,188). This allowed him to avoid the problem of the acausal collapse of the wave-function for individual systems, but reinforced Einstein's belief that quantum-mechanical description is not complete.

98. Physics in My Generation, p.187, and Physics and Politics, p.57 fn. Note the difference between "coexistence" and "coinherence".

99. "Bemerkungen, etc.", p.118 fn., Physics and Politics, p.57 fn., and Natural Philosophy, etc., p.105.

100. See above, ch.2, fn.128, and W.Köhler, Gestalt Psychology, New York, 1929, esp. pp.183-184. For Born's interest in Gestalt psychology see Physics in My Generation, pp.49-50,162, Physics and Politics, p.26. Note, however, that Born regards both wave and particle to be "gestalts" since both are invariants of observation.

101. See ch.2.3 above.

102. The Restless Universe, p.157, "Bemerkungen, etc.", pp. 112-113, Physics and Politics, p.57 fn., Atomic Physics, pp.97-98.

103. Atomic Physics, p.157.

104. "Bemerkungen, etc.", p.113.

105. See our discussion of "equivalence" above, ch.2.5.

106. M.Born and L.Infeld, "Foundations of the New Field Theory", Proc.Roy.Soc.London, Series A, 144, 1934, pp. 425-451.

107. In response to F.Bopp's unitary particle theory; see "Bemerkungen, etc.", pp.116-118. Bopp regarded the wave (function) and particle (event) pictures as equivalent on the phenomenological level of complementarity and indeterminism (i.e. indeterminability, not indeterminedness), but he believed that a purely deterministic, space-time, particle theory could be achieved; see "Quantenmechanische Statistik und Korrelationsrechnung", Zeit.Natur. 20, 1947, pp.210,215,216, and "The Principles of the Statistical Equations of Motion in Quantum Mechanics", in S.Körner, ed., Observation and Interpretation, London, 1957, pp.189-192.

108. The confusion is increased by the fact that Born sometimes adheres to Bohr's usage and refers to waves and particles as being complementary; The Restless Universe, p.162, Physics in My Generation, p.48, "Bemerkungen, etc.", pp.114-115, Atomic Physics, pp.99,103,153.

109. Physics in My Generation, pp.105,160, Physics and Politics, p.30, Natural Philosophy, etc., p.104.

110. Physics in My Generation, p.106, Natural Philosophy, etc., pp.105-106.

111. "The set of these invariants of our sense impressions is the physical reality which our mind constructs in a perfectly unconscious way...Science is nothing else than the endeavour to construct these invariants where they are not obvious." Natural Philosophy, etc., p.104 (contrast The Born-Einstein Letters, p.165); cf. our discussion of invariants in ch.2.2.

112. Possibly Einstein's emphasis on invariance influenced him in this respect; see The Born-Einstein Letters, pp. 164,170,218, and "Albert Einstein und das Lichtquantum", p.430.

113. Physics and Politics, pp.30,56-57, Natural Philosophy, etc., pp.104-105.

114. Physics in My Generation, pp.156,160-161, and Atomic Physics, p.153.

115. Physics in My Generation, pp.160,187, Physics and Politics, pp.29-30; cf. W.Heitler, "The Departure from Classical Thought in Modern Physics", in P.A.Schilpp, ed., op.cit., p.193. Possibly this idea of projections comes from von Neumann's "projection postulate" according to which the physical act of measurement is equivalent to the mathematical projection of the state-vector onto one of its eigen-vectors in Hilbert space. See fn.45 above.

116. See ch.2.2 above.

117. Physics in My Generation, pp.186-187, "Bemerkungen, etc.", pp.114-115, Physics and Politics, pp.30,56-57, Natural Philosophy, etc., p.105. Born also speaks of complementarity between life processes and physico-chemical processes, between body and mind or soul, and between free will and determinism: Physics in My Generation, pp. 52-53,107, Physics and Politics, pp.57-61.

118. Physics in My Generation, pp.160-161, Atomic Physics, p.99, Natural Philosophy, etc., pp.100,108.

119. See pp.67-68 above.

120. Take one pair of conjugate coordinates, q and p, for

simplicity, and let the phase cell have the dimensions a and h/a (where $a \gg h/a$) to satisfy the uncertainty principle for the cases of a pure wave ($\Delta q = a$, $\Delta p = h/a$) and a pure particle ($\Delta q = h/a$, $\Delta p = a$). Then as the phase cell rotates through an angle Θ the uncertainties become $\Delta q \cong a \cos\Theta$ and $\Delta p \cong a \sin\Theta$ so that $\Delta q\, \Delta p \cong a^2 \sin\Theta \cos\Theta$ which is generally much larger than h, the minimum allowed by the uncertainty principle.

121. See ch.2.3 above.

122. e.g. Der Naturwissenschaftler vor der religösen Frage, Oldenburg, 1968.

123. e.g. Anschauliche Quantentheorie, pp.vii-viii. However, Jordan rejected the materialism of P.Frank; ibid, pp. viii-ix,273.

124. Physics of the Twentieth Century, New York, 1944, pp. 46,115,123,149.

125. ibid, p.159. For Born's comments on Jordan's "positivism" see Physics in My Generation, pp.48-49, Physics and Politics, p.18.

126. Especially K.Popper; see ch.1, fn.9.

127. e.g. "Quantenphysikalische Bemerkungen zur Biologie und Psychologie", Erkenntnis 4, 1934, p.244; cf. p.232. Bohr may well have had Jordan's statements in mind when he warned against such language (see ch.1, fn.127 above).

128. e.g. "Die Quantenmechanik und die Grundprobleme der Biologie und Psychologie", Naturwis. 45, 1932, p.818. Jordan apparently equated "objectivity" with causality and continuity after Kant; see Physics of the Twentieth Century, pp.124,145.

129. "Quantenphysikalische Bemerkungen, etc.", p.233, Physics of the Twentieth Century, pp.130,137.

130. "On the Process of Measurement in Quantum Mechanics", Phil.Sci. 16, 1949, pp.269-278; cf. ch.2, fn.69 above. Jordan had earlier worked with von Neumann and Wigner; P.Jordan, J.von Neumann, and E.Wigner, "On an Algebraic Generalization of the Quantum Mechanical Formalism", Annals of Mathematics 35, 1934, pp.29-64.

131. "On the Process of Measurement, etc.", p.276. Note: Jordan follows Szilard in regarding the concepts of temperature and entropy to be applicable to individual atoms. We have assumed (ch.3.1) with most physicists that these features only emerge with large numbers of atoms.

132. See ch.2, fn.68 above.

133. See ch.2, fns. 78 and 80 above.

134. This analogy had been previously suggested by Jordan ("Über eine neue Begründung der Quantenmechanik", _Zeit.Phys._ 40, 1927, pp.809-838) and developed by von Neumann (_op.cit._, p.218, fn.125).

135. "On the Process of Measurement, etc.", p.277.

136. If our interpretation is correct, then Jordan's "thermodynamic complementarity" is related to the "wave-mechanical complementarity" and is not entirely as independent as Jordan supposes; cf. fn.131 above.

137. "Die Quantenmechanik, etc.", p.819 fn. Note that this was published the same year that Bohr gave his "Light and Life" address.

138. _ibid_, p.820, _Die Physik und das Geheimnis des organischen Lebens_, Braunschweig, 1945, pp.83,86, _Verdrängung und Komplementarität_, p.44.

139. "Quantenphysikalische Bemerkungen, etc.", pp.236-238, _Physics of the Twentieth Century_, p.152.

140. _Die Physik und das Geheimnis, etc._, p.124.

141. "Die Quantenmechanik, etc.", p.820.

142. _ibid_, p.821.

143. _ibid_, p.819, _Physics of the Twentieth Century_, p.153.

144. "Quantenphysikalische Bemerkungen, etc.", p.249, _Physics of the Twentieth Century_, p.130.

145. See above, p.23.

146. Verdrängung und Komplementarität, pp.9,45, _Der Naturwissenschaftler, etc._, p.347.

147. "Quantenphysikalische Bemerkungen, etc.", p.248. The reference is to Freud's _Vorlesungen zur Einführung in die Psychoanalyse_ (_Gesammelte Werke, Elfter Band_), Vienna, 1924, p.288 (reprinted London, 1940).

148. _Verdrängung und Komplementarität_, pp.45-47, _Der Naturwissenschaftler, etc._, pp.345-348.

149. _Der Naturwissenschaftler, etc._, p.345.

150. See ch.1, fn.43 above on James's theory of hysteric diseases.

151. "My philosophical attitude in this inquiry is positivistic and operational to the limits of the possible. It is not too much to say that every sentence (with the

exception of a few brief excursions into philosophical generalization) has been carefully surveyed so as to be operational, that is to have a definite meaning in terms of laboratory or other observational procedures." The Physical Foundation of Biology, p.viii; cf. Atom and Organism, pp.v-vi.

152. The Physical Foundation of Biology, p.5, esp.fn.

153. Atom and Organism, pp.8-9,13,18,24,29,30,42,48,109,119, 121. Elsasser took this "frequency definition" from von Neumann (op.cit., p.298, fn.156) who in turn took it from R.von Mises (Probability, Statistics, and Truth, London, 1939, p.308). The "ensembles" or "collections" are composed of identical, non-interacting systems; see ch.3, fn.14.

154. "On Quantum Mechanical Measurements and the Role of the Uncertainty Relations in Statistical Mechanics", Phys. Rev. 52, 1937, pp.987-999; see esp. p.989.

155. See above, ch.3, fn.4.

156. The line of reasoning which follows is taken from loc. cit., pp.988-990.

157. i.e. "Γ - space" for which there are six dimensions (three position coordinates and three momentum coordinates) for each atom; see K.Huang, op.cit., p.75.

158. One could measure the wave-functions of all members of the ensemble save one and use the results to statistically determine the wave-function of that one. The only requirement would be that the number of systems in the ensemble be much larger than the possible number of wave-functions. It is this condition that breaks down for the finite classes of biology; see The Physical Foundation of Biology, pp.150-160.

159. "On Quantum Mechanical Measurements, etc.", p.989; cf. E.T.Jaynes, "Information Theory and Statistical Mechanics II", Phys.Rev. 108, 1957, p.176.

160. e.g. loc.cit., p.990.

161. ibid; cf. The Physical Foundation of Biology, pp.148, 149, "Quanta and the Concept of Organismic Law", J.Th. Biol. 1, 1961, pp.34,39, Atom and Organism, pp.22,114, "The Mathematical Expression of Generalized Complementarity", p.279. Note that Elsasser virtually equates complementarity with reciprocity (the uncertainty principle) and neglects such features as completeness, alternation and emergence; "On Quantum Mechanical Measurements, etc.", p.988, The Physical Foundation of Biology, pp.147-148,165,170-172, "Quanta and the Concept of Organismic Law", p.34, Atom and Organism, p.17, and "The Mathematical Expression, etc.", pp.278,279,281.

162. "On Quantum Mechanical Measurements, etc.", p.990. The reason they need not perturb the system is that wavelength is not correlated with momentum in classical physics.

163. See pp.88f above.

164. contra A.Grünbaum (loc.cit., pp.714-715) who claims that two parameters may be operationally compatible and yet theoretically incompatible. While the possibilities of observation and definition must be distinguished for methodological purposes they cannot be separated.

165. See ch.1.3 above.

166. "What is Theoretical Biology?" in M.Marois, ed., op. cit., p.74.

167. e.g. The Physical Foundation of Biology, pp.9,13, Atom and Organism, pp.vii,21-22.

168. The Physical Foundation of Biology, pp.149-150,160,213.

169. Due to misunderstandings of this term Elsasser later replaced it by the term "epigenetic"; see "Physical Aspects of Non-Mechanistic Biological Theory", J.Th. Biol. 3, 1962, p.165, Atom and Organism, p.128.

170. The Physical Foundation of Biology, pp.148,149, "Quanta and the Concept of Organismic Law", p.43, "Max Borns Kritik der mechanischen Vorsagbarkeit und die theoretische Biologie", Zeit.Phys. 171, 1962, pp.67-68, Atom and Organism, pp.17-18, and "The Mathematical Expression, etc.", p.281.

171. The Physical Foundation of Biology, pp.149-150, Atom and Organism, p.19.

172. The Physical Foundation of Biology, pp.150,160, "Quanta and the Concept of Organismic Law", pp.39,43, Atom and Organism, pp.18,30-31,36.

173. The number of system-events is 10^{72}, hence its logarithm is 72 (Atom and Organism, pp.76-77). The logarithm of the number of microstates, on the other hand, is more than 10^{11} (ibid, p.69); cf. The Physical Foundation of Biology, p.159, "Quanta and the Concept of Organismic Law", pp.40-41, "The Mathematical Expression, etc.", pp.293-294.

174. Atom and Organism, pp.42,109.

175. See above, p.94, esp. fn.46. It is true that Bohr stressed individual rather than class complexity; cf. The Physical Foundation of Biology, pp.149-150, "Note on Evolution is Organismic Theory", J.Th.Biol. 4, 1963, p.168, Atom and Organism, p.18.

176. The size of the presently known universe would have to be increased by the immense factor whose logarithm is more than 10^{11}. Of course, a steady-state universe would be infinite in size, but all the stars and planets beyond a certain distance (about ten billion light years) would be travelling away from us at speeds greater than that of light, hence they would be inaccessible to us in principle. For a good review of the alternate cosmological theories see e.g. J.Singh, Modern Cosmology, London, 1970.

177. In a steady-state universe there would be no such limitation since the process of creation would have been going on forever. But see R.Schlegel, Completeness in Science, New York, 1967, pp.138-143.

178. It appears that life on earth will be destroyed when the sun becomes a red giant in another five or six billion years. The same fate would presumably await any life in other planetary systems. But even if some form of life were intelligent enough to escape such a disaster and find a new supply of energy to replace its "sun" it would eventually run out of suns unless the universe is in a steady-state and new suns are continually being created. But it is difficult to see how limitations such as these could affect the nature of life itself.

179. At the same time present forms of life would have to become extinct.

180. "On Quantum Mechanical Measurements, etc.", p.990, Atom and Organism, pp.42,90, "The Mathematical Expression, etc.", p.277.

181. "Quanta and the Concept of Organismic Law", p.41, Atom and Organism, pp.33-34,81,82, "The Role of Individuality in Biological Theory", in C.H.Waddington, ed., Towards a Theoretical Biology: 3. Drafts, Edinburgh, 1970, p.144.

182. "The Role of Individuality, etc.", p.137.

183. The Physical Foundation of Biology, p.169, "Quanta and the Concept of Organismic Law", p.51, "Physical Aspects, etc.", pp.178-180, "Synopsis of Organismic Theory", J. Th.Biol. 7, 1964, pp.64-65, "Semiformal Representation of Organismic Concepts", Proc.Nat.Acad.Sci. 54, 1965, pp.1432-1433, Atom and Organism, pp.79-82,109, and "The Mathematical Expression, etc.", pp.294-295; cf. above fn.138 and ch.3, fn.101.

184. "The Role of Individuality, etc.", p.139.

185. On the distinction between quantitative rarity and qualitative individuality, see R.J.Pendergast, Cosmos, New York, 1973, p.2. Pendergast's hierarchical, anti-reductionist cosmology is in many ways similar to ours except that is is deterministic and idealistic in its emphasis (see e.g. pp.19,83).

186. In fact, a rough estimate of the total number of possible macrostates (equivalent microstate groupings) of a single cell shows that only an immensely small percentage of these can be realized during the lifetime of an organism.

187. Atom and Organism, pp.50-51,53,57,78,110,134, and "The Mathematical Expression, etc.", p.295.

188. The Physical Foundation of Biology, pp.13,122,142-143, 150, and "Physical Aspects, etc.", p.169; cf. P.A.Weiss, "The Living System: Determinism Stratified", in A. Koestler and J.R.Smythies, eds., Beyond Reductionism, London, 1969, pp.3-55. This argument is completely misunderstood by F.Crick, Of Molecules and Men, Seattle, 1966, pp.20-21, and by K.F.Schaffner, "Antireductionism and Molecular Biology", Science 157, 1967, p.645.

189. See ch.2.10 above.

190. See fn.161 above.

191. On Bohr's differences with the Vienna Circle, and Frank in particular, see W.Heisenberg, Physics and Beyond, pp.205-208,210.

192. Frank's principal writings on complementarity are: Interpretations and Misinterpretations of Modern Physics, Paris, 1938, Modern Science and Its Philosophy, Cambridge, Mass., 1949, "Foundations of Physics", in O.Neurath et al., eds., op.cit., esp. pp.475-482, and Philosophy of Science, Englewood Cliffs, 1957.

193. Interpretations, etc., pp.31-32, Modern Science, etc., pp.170-171,246.

194. Interpretations, etc., pp.31-32, "Foundations of Physics", p.476, and Modern Science, etc., p.179.

195. "Meaningless metaphysical propositions immediately arise if one say that 'reality' itself is 'dual' or displays 'different aspects'." Modern Science, etc., p.165; cf. Interpretations, etc., pp.14,20, "Foundations of Physics", p.481, and Philosophy of Science, p.244.

196. Interpretations, etc., p.15, "Foundations of Physics", p.482, Modern Science, etc., p.164.

197. Modern Science, etc., pp.179-180.

198. Interpretations, etc., p.27, Modern Science, etc., pp. 168,170.

199. Interpretations, etc., p.26, Modern Science, etc., pp. 169-170.

200. Interpretations, etc., p.21, Modern Science, etc., pp. 168-169.

201. See ch.1.3 above.

202. _Interpretations, etc._, pp.28-29.

203. _ibid_, pp.25,28-29.

204. _ibid_, pp.21-23, and _Modern Science, etc._, pp.166,168.

205. _Interpretations, etc._, pp.22-23, _Modern Science, etc._, p.167; cf. J.R.Lucas, _The Freedom of the Will_, Oxford, 1970, pp.14-16.

206. _Modern Science, etc._, p.167.

207. See ch.1, fn. 110 above.

208. A.Sommerfeld, "Wege zur physikalischen Erkenntnis", _Scientia_ 59, 1936, p.187.

209. _Interpretations, etc._, p.17.

210. Polanyi's writings have done much to change this; e.g. _The Tacit Dimension_, pp.38-40; but see J.H.Woodger, _op.cit._, (1929), p.263.

211. See above, pp. 103f.

212. _Philosophic Foundations of Quantum Mechanics_, pp.26-44, 139-148, "The Principle of Anomaly in Quantum Mechanics", _Dialectica_ 2, 1948, pp.337-350 (reprinted in H.Feigl and M.Brodbeck, eds., _Readings in the Philosophy of Science_, New York, 1953, pp.509-520), _The Rise of Scientific Philosophy_, Berkeley, 1951, pp.183-189, _The Direction of Time_, pp.216-218.

213. "Interphenomena" are unobserved events imagined to take place between the observed "phenomena".

214. See our discussion of equivalent pictures above, ch.2.5.

215. Reichenbach undoubtedly had Bohr's restriction to well-_defined_ phenomena in mind, but he misunderstood it as a restriction to _observed_ phenomena; see above, ch.1, fns. 124-127.

216. See above, ch.2.6. Note the distinction between complementary modes and equivalent pictures.

217. See above, p.140.

218. _Philosophic Foundations, etc._, p.42.

219. _ibid_, p.40.

220. J.A.Wheeler and R.P.Feynman, "Interaction with the Absorber as the Mechanism of Radiation", _Rev.Mod.Phys._ 17, 1945, pp.157-181, "Classical Electrodynamics in

Terms of Direct Particle Interaction", Rev.Mod.Phys. 21, 1949, pp.425-433; and R.P.Feynman, "Space-Time Approach to Non-Relativistic Quantum Mechanics", Rev. Mod.Phys. 20, 1948, pp.367-387, and "Space-Time Approach to Quantum Electrodynamics", Phys.Rev. 76, 1949, pp. 769-789.

221. A.Einstein, "Relativity and the Ether", in The World As I See It, pp.193-204.

222. "Interaction with the Absorber, etc.", pp.158-160.

223. ibid, pp.159-160,181.

224. ibid, pp.157 fn., 158, "Classical Electrodynamics, etc.", p.425, "Space-Time Approach to Quantum Electrodynamics", p.770; cf. W.H.McCrea, "Action at a Distance", p.76. F.J.Dyson concludes that Schwinger's field-theoretical approach and Feynman's particle-interaction approach are complementary: "The S Matrix in Quantum Electrodynamics", Phys.Rev. 75, 1949, p.1736.

225. "Space-time Approach to Quantum Electrodynamics", pp. 770-771; cf. "Classical Electrodynamics", p.426.

226. R.P.Feynman, "The Theory of Positrons", Phys.Rev. 76, 1949, pp.749-759.

227. See above, ch.2.5.

228. H.Everett III, "'Relative State' Formulation of Quantum Mechanics", Rev.Mod.Phys. 29, 1957, pp.454-462; J.A. Wheeler, "Assessment of Everett's 'Relative State' Formulation of Quantum Theory", ibid, pp.463-465; for a semi-popular review see B.S.de Witt, "Quantum Mechanics and Reality", Physics Today 23 (No.9), 1970, pp.30-35.

229. H.Everett III, loc.cit., p.454.

230. See ch.1, fn.29 above.

231. See p. 148 above.

232. J.von Neumann, op.cit., p.421.

233. H.Everett III, loc.cit., pp.455-456.

234. ibid, p.459.

235. ibid, p.462.

236. J.A.Wheeler, loc.cit., pp.463-464.

237. B.S.de Witt, loc.cit.

238. J.A.Wheeler, loc.cit.

239. See e.g. "A Septet of Sibyls: Aids in the Search for Truth", American Scientist 44, 1956, pp.360-377, and "Science and Survival", in B.Baumrin, ed., The Delaware Seminar on the Philosophy of Science, Vol.2, 1962-1963, New York, 1963, pp.483-523.

240. "Assessment of Everett's 'Relative State' Formulation of Quantum Theory", pp.463-464.

241. ibid, p.464.

242. Not to be confused with K.M. Meyer-Abich.

243. "The Principle of Complementarity in Biology", Acta biotheoretica 11, 1955, pp.60-65.

244. ibid, pp.66-69; cf. A.Koestler's polarity between self-assertive and integrative tendencies of "holons": The Ghost in the Machine, London, 1967, ch.3, and "Beyond Atomism and Holism - The Concept of the Holon", in A. Koestler and J.R.Smythies, eds., op.cit., pp.192-232. Recently Koestler has related this polarity to complementarity (The Roots of Coincidence, London, 1972, p. 113). However, he regards it as a static equilibrium between opposing forces rather than a dynamic alternation between complementary modes.

245. See above, pp. 95ff.

246. See above, pp. 107f.

247. e.g. symbiotic relationships between organisms; see above p. 107.

248. loc.cit., pp.69-71. Meyer-Abich actually speaks of heredity and adaption being complementary, but the context shows that he means selection and adaption as two complementary mechanisms of heredity and evolution.

249. cf. Bohr's treatment of teleological ideas and the terminology of molecular biology; see ch.3, fn. 48 above. See also A.Koestler, The Ghost in the Machine, chs.10 and 11.

250. See p. 3 above.

251. H.Bedau and P.Oppenheim, "Complementarity in Quantum Mechanics: A Logical Analysis", Synthese 13, 1961, pp. 201-232; N.Brody and P.Oppenheim, "Application of Bohr's Principle of Complementarity to the Mind-Body Problem", J.Phil. 66, 1969, pp.97-113; S.Lindenberg and P.Oppenheim, "Generalization of Complementarity and Its Application to the Field of Secular and Religious Apprehensions", and H.Bedau, "Complementarity and the Relation between Science and Religion", two papers delivered at the First Birmingham Conference on the Philosophy of Religion, April, 1969.

252. H.Bedau and P.Oppenheim, loc.cit., p.224.

253. Note that this is not the same as Bohr's definition of the word "phenomenon" (see ch.1, fn.124). For Bohr the phenomena require experimental conditions for their definition whether they are observed or not, i.e. whether they are observed "phenomena" in Reichenbach's sense or unobserved "interphenomena" (see fns.213,215 above).

254. H.Bedau and P.Oppenheim, loc.cit., pp.202,211-212,216, 221-223.

255. ibid, pp.213,216,219,224.

256. ibid, p.216; N.Brody and P.Oppenheim, loc.cit., p.98.

257. See fn.253 above.

258. N.Brody and P.Oppenheim, loc.cit.

259. ibid, p.101.

260. ibid, pp.101-102.

261. ibid, pp.102-104.

262. If Oppenheim et al. had not made the artificial distinction between theory-free and theory bound entities they probably would have thought of better examples!

263. N.Brody and P.Oppenheim, loc.cit., pp.105-109.

264. See above, ch.3, fn.81.

265. See above, ch.3, fn.73.

266. So P.K.Feyerabend, "Niels Bohr's Interpretation of the Quantum Theory", p.371, "Problems of Microphysics", p. 221, and "On a Recent Critique of Complementarity I", p.310.

Chapter 5

Bohr's Critics on Complementarity

> "...Some versions [of the 'Copenhagen Point of View'] which are discussed at great length in the literature are not even a real thing but an artitrary construction on the part of certain philosophers and scientists who in their eagerness to prove Bohr wrong have collected prima facie absurd statements [of Bohr's] wherever they could find them, without regard for context, or for idiosyncrasy of expression."
> P.K.Feyerabend, "On a Recent Critique of Complementarity I", p.310.

We shall treat Bohr's critics in three groups: (a) founders of quantum theory (Planck, Einstein, Schrödinger, de Broglie), (b) contemporary physicists who challenge the "Copenhagen interpretation" with interpretations or even new theories of their own (de Broglie, Bohm, Margenau, Landé), and (c) philosophers of science who challenge Bohr primarily on philosophical grounds (Popper, Bunge, Feyerabend).

5.1 Max Planck:

Max Planck is generally regarded as the founder of modern physics due to his discovery of the quantum of action (Planck's constant) at the turn of the century,[1] but his views on quantum theory and his philosophy in general have been overshadowed by those of Einstein, Bohr and others. He was an outspoken opponent of positivism long before such opposition became fashionable, and he greatly influenced the philosophical development of Einstein's thought in this respect.[2] Planck's basic philosophy was similar to the

Aristotelian essentialism which the positivists opposed,[3] but it was sometimes modified along Popperian "hypothetico-deductive" lines, emphasizing the importance of "free creation" along with Einstein's.[4] At times Planck even spoke of causality as an a priori category in the Kantian sense and based his arguments for determinism on the necessity of presupposing strict causality in all science.[5]

Planck never addressed himself directly to the ideas of Niels Bohr or to the principle of complementarity.[6] He was generally opposed to the "Copenhagen interpretation" because of its failure to maintain strict determinism in the "real world". There is an appearance of indeterminism, he conceded, due to the tenuous connection between the metaphysical and phenomenological realms, but the real, unobservable wave-function obeys strictly causal laws (Schrödinger's equation) and hence is deterministic.[7] In this respect Planck's outlook is almost identical to that of Heisenberg![8] How two physicists with such diverse philosophical presuppositions could arrive at such similar conclusions would make an interesting study in itself. The only common denominator seems to be their common interest in Kant and their desire to preserve the form of causality even at the expense of endless abstraction.[9]

In spite of all this there are some striking parallels in Planck's writings to Bohr's principle of complementarity, particularly with regards to the problem of free will and determinism. Almost every volume of Planck's essays contains some treatment of this problem.[10] The basic idea is simple: free-will and determinism are perfectly compatible because they involve viewpoints which are mutually exclusive. The viewpoint of determinism requires strict objectivity, hence it can only be applied to the actions of others or else to one's own past actions, but never to one's present or future decisions. The latter are "free" in this sense.[11] In Planck's words: "Observed from without, the will is causally determined. Observed from within, it is free."[12] The deterministic viewpoint of science, therefore, requires the voluntaristic viewpoint of ethics as its "complement".[13] The same relation holds between a physiological event like a pinprick and its psychological correlate, the sensation of pain. Their analysis requires two different methods which mutually preclude each other, and neither can be eliminated or reduced to the other.[14] In fact, Planck even treats the wave-particle duality for electrons as an example of alternate viewpoints.[15] He never refers to these viewpoints as complementary, however; instead, he seems to have regarded them as being "orthogonal" in our sense of the term.[16] In other words, for Planck, the two viewpoints are mutually exclusive in experience, but not in reality.[17] The contrast to Bohr's position is clear, but the strong similarity is also striking. Planck's treatment is closer to Bohr's in many respects than are the treatments of most of Bohr's supposed allies!

5.2 Albert Einstein:

We have already compared Einstein's philosophy of science as a whole to that of Niels Bohr,[18] so now we should concentrate on Einstein's attitude toward complementarity in particular. It appears that Einstein did not know what to make of Bohr, perhaps because their general approaches were so radically different. He greatly admired Bohr's physical intuition[19] and once said that, of all the "orthodox" quantum theorists he knew, Bohr came the nearest to achieving a satisfactory treatment of the philosophical questions in quantum physics.[20] On the other hand, Einstein found Bohr's explanations of complementarity to be abstruse and unclear, and he seems to have misunderstood Bohr as basing his arguments on the limits of measurement rather than questions of principle.[21] Moreover, there were several presuppositions in Einstein's outlook which ruled out complementarity from the start and made it virtually impossible for him to appreciate Bohr's thinking, much less agree with it. The question of determinism, however, was <u>not</u> the primary issue. Determinism was as much a by-product of Einstein's general field-theoretical approach as indeterminism was of Bohr's pluralistic view of correspondence and complementarity.[22] The primary issues were those of (a) continuity and (b) contiguity. (a) Einstein believed that nature must be ultimately continuous in space and time hence he was dissatisfied with the ideas of "quantum-jumps" and a wave-function which collapses discontinuously.[23] From the viewpoint of complementarity these discontinuities are associated with transitions from the wave-mode to the particle-mode and their elimination would require the elimination of the particle-mode, i.e. the repudiation of complementarity itself. (b) A primary motivation for Einstein's development of a relativistic field theory was his desire to eliminate all action at a distance and replace it by a form of action by contact.[24] Thus he regarded the "principle of contiguity" as a necessary condition for all scientific theories.[25] From the viewpoint of complementarity the elimination of action at a distance implies that the state of an object can be defined independently of its immediate environment, since the interaction between object and environment can then be analyzed in terms of some kind of force-field, and an object-in-itself can be abstracted.[26] Then the specification of the experimental arrangement would no longer be essential, and the manifestation of modes like wave and particle would only be apparent.[27] It should be clear that the difference between Einstein and Bohr was not a matter of physics so much as philosophy. As we noted in our discussion of their general positions, they saw the world in completely different ways.[28]

5.3 Erwin Schrödinger:

Like Einstein, Schrödinger was a lifelong opponent of the idea of discontinuity in quantum theory and particularly of the "quantum-jump".[29] In fact, it was partly the desire to provide a continuous description of atomic transitions that led him to develop wave mechanics in the first place.[30] In September 1926 Bohr invited Schrödinger to Copenhagen to discuss their differences, but no agreement was ever reached.[31] As in the Bohr-Einstein discussions there was simply too much of a divergence in outlook to allow mutual understanding.

Schrödinger never discussed Bohr's principle of complementarity, at least not in print. However, one of his expositors, W.T. Scott, has suggested that he developed a version of complementarity of his own.[32] The idea Scott refers to is Schrödinger's distinction between the longitudinal and transversal continuities of material waves.[33] Transverse continuity corresponds to the wave-fronts perpendicular to the direction of propagation and manifests itself in diffraction patterns and other interference phenomena. Longitudinal contiguity corresponds to the wave-normals pointing in the direction of propagation and manifests itself in the "particle-tracks" that are visible in cloud chambers and photographic emulsions. Schrödinger pointed out that both of these aspects are equally real and that they correspond to wave-like and particle-like behavior, respectively. However the analogy to complementarity is only superficial: a "particle-track" actually consists of a long sequence of point-like events which are connected by the conservation of momentum between the events and appear like a continuous track when magnified by amplification techniques. So Schrödinger's "longitudinal continuity" is only an apparent continuity which involves both wave and particle modes in rapid alternation. The same is true for the "transversal continuity" of diffraction experiments.[34] Schrödinger, of course, knew all this,[35] but he insisted on a world-view in which discontinuities are completely camouflaged.[36] All discreteness and plurality could only be an appearance for him since ultimate reality is organic and non-plural.[37] Clearly, his viewpoint was incompatible with Bohr's from the start.

5.4 Louis de Broglie:

Certainly one of the most colorful and imaginative thinkers in modern physics has been Louis de Broglie. An entire thesis could be devoted to the course of his complex development, but here we can at least distinguish the three principal stages:[38] (a) 1923-1927, as one of the founders and principal interpreters of the quantum theory, (b) 1928-1950, as a convert to the Copenhagen view, influenced by Bohr, Heisenberg and Born, and (c) since 1951, as an outspoken critic of the Copenhagen school, influenced by D.Bohm and J.P. Vigier.

(a) <u>1923-1927</u>: It was de Broglie who first associated a "matter-wave" with each material particle and so introduced the "wave-particle duality" into the theory of matter as well as radiation.[39] However, as de Broglie himself explained, he had intended to unify the wave and particle aspects, not to introduce a new dichotomy.[40] This primary motivation gives some coherence to his subsequent vagaries. During 1926-1927 he became dissatisfied with the Schrödinger representation of matter-waves by the wave function which was then interpreted statistically by Born, and he developed a "theory of the double-solution". Here one solution was Schrödinger's wave-function which determined the probabilities of particle-events, but the second solution contained a point singularity representing the particle itself and so determined the occurrence of particle-events in a quasi-classical manner.[41] Due to the mathematical difficulty of this theory de Broglie simplified it into a "pilot-wave" theory in which the Schrödinger wave-function itself guided the motion of the particle. However, this reintroduced the dualism of wave and particle which he had hoped to avoid so when the pressure of criticism rose he abandoned these efforts and tried to live with the orthodox statistical interpretation for the next thirty years.[42]

(b) 1928-1950: It was during this period that de Broglie made several interesting contributions to the discussion about complementarity. We shall not dwell on his occasional regurgitations of half-digested ideas he had picked up from Bohr et al. - de Broglie was obviously uneasy about many aspects of the Copenhagen line.[43] But he also made several attempts to rethink complementarity along purely rational lines that he could visualize and understand. De Broglie clearly recognized his own difficulty in appreciating Bohr's approach - he later referred to Bohr as the "Rembrandt of contemporary physics"[44] - and openly acknowledged his own "secret hankering after Cartesian clarity".[45] Complementarity, he finally decided, was a "mystery",[46] and he never gave up the hope that some new idea would be discovered which would provide a more lucid interpretation of the "wave-particle duality".[47] Yet, at the same time, the notion of complementarity intrigued him and he spent a good deal of time trying to make sense out of it.

His first, most ingenuous attempt was by analogy to an optical instrument which could focus on either of two objects (at different distances from the eye) but only on one object at a time.[48] The two objects represent position (the particle-mode) and momentum (the wave-mode) only one of which can be accurately determined at a time according to the uncertainty principle. Classical mechanics, de

Broglie said, was like a rather crude lens which seemed to focus on both at the same time, but more refined tools (quantum mechanics) show this to be impossible. The problem with this analogy, of course, is that it leaves one with the suspicion that both objects exist simultaneously even if they cannot be perceived simultaneously, and hence it suggests that complementarity is really subjective. Also, there is a suggestion of dualism since two objects rather than one are involved. Both of these difficulties could have been avoided if de Broglie had chosen an audio rather than a visual model. For instance, a radio might be able to tune in to one of two nearby resonant frequencies, but only one at a time. Then there would be a single audio output existing in one of two modes. Ultra high frequency television could also be used as an example combining both audio and visual. However, all such analogies are somewhat artificial, and they do not satisfy the conditions of alternation, emergence and pointing.

De Broglie's favorite example of complementarity was the relationship between individual particles and the system which they compose.[49] If the particles do not interact strongly with each other (i.e. if the potential energy is much less than the total rest-mass energy) then the system can easily be analyzed into its parts and the total mass energy can be divided up among them. But for strong interactions with relativistic potential energies such an analysis can be performed only at the expense of destroying the unity of the system.[50] Hence the "system" can either function as a whole or be analyzed into its parts, though not both at the same time. De Broglie called these the modes of "interaction" and "individuality", respectively.[51] However, as de Broglie saw it, both of these modes were really "abstract idealizations" and the reality was always intermediate between them.[52] If this were true then complementarity would not be an appropriate concept here, because complementary modes are mutually exclusive and coexhaustive. However, it appears that de Broglie may have been thinking of the degree of interaction between the particles as being intermediate between the nonrelativistic and relativistic cases rather then the system itself being intermediate between the two modes that emerge in the relativistic case. The former sort of intermediacy is quite consistent with the logic of complementarity; for example, the emergence of complementarity in thermodynamics depends on the number of molecules in a system (compared with Avogadro's number),[53] that in biology depends on the degree of inhomogeneity,[54] and that in psychology may depend on the weight and complexity of the brain. Even the emergence of complementarity in atomic physics (i.e. the emergence of atomic stability) depends on the temperature and radiation pressure of the environment.[55] Hence we may expect that the emergence of de Broglie's complementarity will depend on the degree of interaction, but insofar as this degree is large the system will exist in two mutually exclusive modes which do not allow any intermediate representations. With this one amendment, de Broglie's idea is extremely plausible and could turn out to be important in relativistic quantum mechanics. Quel dommage that de Broglie never fully devoted himself to the development of these ideas![56]

(c) Since 1951: As we have observed, de Broglie was never really comfortable with the concept of complementarity. In his own words he "secretly hankered after Cartesian clarity in the midst of the fog which seemed to envelop quantum physics".[57] In the years 1951-1952 he received communications from both Bohm[58] and Vigier[59] which encouraged him to take up his "theory of the double solution" once more. This time he defied the mathematical complexity and began looking for solutions for non-linear equations in keeping with a suggestion made by Einstein.[60] The effect of non-linearity would be to represent particles as localized inhomogeneities rather than point singularities, thus avoiding the mathematical infinities that have plagued quantum electrodynamics.[61] Then de Broglie "grafted" this non-linear solution representing the particle onto a linear solution representing the wave, thus uniting the wave and particle concepts as he had first intended.[62] Finally, he tried to account for the apparent randomness of particle-events by including a "subquantic medium" which buffets the particles just as invisible molecules buffet droplets of liquid in Brownian motion.[63] One tends to wonder where all this is leading, but de Broglie is confident that these ideas can be "suitably developed and corrected" so as to provide a real alternative to the orthodox interpretation of quantum mechanics[64] and that the imported randomness can be reduced to a hidden determinism.[65] Only time will tell.

What is de Broglie's current opinion of complementarity? He regards it as an artificial dichotomy between extreme cases which never actually occur in nature.[66]

Reality is always intermediate (not a very Cartesian idea), therefore the ideas of wave and particle should be fused together rather than set in opposition. De Broglie's revised "double solution" provides just such an intermediate model: the non-linear part gives localized particle-like events such as impacts on a screen, and the linear part gives non-localized wave-like phenomena such as diffraction patterns. Since both parts are always present, there is no need for the quantum gymnastics of collapse and reexpansion which a simple wave-function like Schrödinger's must go through. Instead of an inherently dynamic reality which exists in alternate modes of being, there is a more invariant reality which manifests alternate parts of itself at different times. Hence de Broglie would say that an electron is both wave and particle at the same time,[67] or else that is is really neither wave nor particle, but something in between the two.[68]

In my opinion, this composite model of de Broglie's represents one of the most serious challenges to orthodox quantum theory today. However, it cannot be properly evaluated until it is worked out in detail, and de Broglie may have opened Pandora's box by appealing to a subquantic medium so a complete formulation may be a long time coming.

5.5 David Bohm et al.:

More than any other contemporary physicist, David Bohm has carried on Bohr's emphasis on the priority of physical insight over mathematical formalism. Bohm's work can be divided into three periods: (a) before 1951, as an advocate of complementarity, influenced by Bohr, (b) the

1950's, developing various "hidden variable" theories, influenced by Einstein and Vigier, and (c) the 1960's to present, as a natural philosopher, influenced again by Bohr and Jeffrey Bub.

(a) before 1951: Bohm's work up till 1951 is epitomized by his classic Quantum Theory.[69] In this treatise he presents the orthodox interpretation in clear, physical terms with a minimum of mathematics.[70] His treatment of complementarity is particularly good; it is much clearer than Bohr's though not as sophisticated. He places great stress on the indivisibility of an atomic system and its environment,[71] the relational (i.e. non-intrinsic) quality of atomic properties (e.g. position and momentum),[72] the full equality of wave and particle modes,[73] the alternation between modes in temporal evolution,[74] and the latency or potentiality of each mode within the other.[75] In an attempt to visualize these points Bohm offers an analogy to the evolution (ontogenetic) of a bacterium by alternation between the bacterial and spore stages.[76] In both stages we have the same living system, but two completely different organic structures. However, as Bohm points out, the alternation simply involves a rearrangement of the various parts of the bacterium and its environment and is not intrinsic to the nature of the bacterium as it is for an electron alternating between wave and particle modes. In other words, the laws of operation for a bacterium and a spore are basically the same and there is no real "emergence" from one to the other.

There is one serious fault in Bohm's view of complementarity. Towards the end of Quantum Theory he discusses the relationship of classical and quantum concepts as an example of complementarity even though this relation does not satisfy the very criteria which he had stressed himself![77] The problem is that he completely neglects Bohr's principle of correspondence which is essential to a proper understanding of complementarity, at least in a unique universe.[78]

The most striking feature of Quantum Theory is Bohm's curious preoccupation with the problem of "hidden variables".[79] He suggests an analogy between the possible reduction of quantum mechanics to a hidden variable theory and the 19th century "reduction" of thermodynamics to the statistics of atoms and molecules.[80] He concluded that there was no point in searching for hidden variables until the current quantum theory broke down,[81] but the analogy to thermodynamics must have seemed too good to neglect for he soon changed his mind.[82] Actually Bohm's analogy is very similar to Bohr's analogy between thermodynamics and quantum mechanics except that for Bohr the relationship between the two levels (thermodynamic and mechanical, or wave and particle)[83] was one of complementarity rather than reduction. In other words, Bohm's view of physics is hierarchical like Bohr's, but it is more unified and reductionist.[84]

(b) the 1950's: We cannot possibly go into all the hidden variable theories that Bohm and his colleagues have developed.[85] Instead we shall concentrate on Bohm's criticisms of complementarity during this period. The basic points are that complementarity does not allow a complete, continuous, strictly causal description of atomic processes[86] and that the relationship between wave and particle lacks real unity.[87] Bohm even calls the transition from one mode to the other a form of magic since "the precise details...are necessarily forever beyond human comprehension"![88] As for causality: Bohm now claims that "the domain of causality defines the domain of science itself" and goes on to argue that causality can always be profitably assumed, whether it really exists or not, in a manner reminiscent of Pascal's wager.[89] But the worst of it is that Bohm commits the "unforgivable sin" of attributing the uncertainty principle to practical limitations of measurement rather than considerations of principle.[90] It may be, as he predicts, that the uncertainty principle (and complementarity) will have to be modified in the nuclear domain (10^{-13} cm.),[91] but that is no excuse for distorting the arguments that led to it in the first place.[92] I frankly do not understand why Bohm changed his mind about complementarity: his pre-1951 arguments for it are far more cogent than his post-1951 arguments against it. Perhaps it was, as he sometimes said, just to give the orthodox interpretation some healthy competition.[93]

(c) the 1960's to present: Since about 1962 Bohm has diversified his interests into many areas of theoretical physics and natural philosophy in general. The important point for our consideration is his renewed interest in Niels Bohr. Since his 1962 critique of Heisenberg's Physics and Philosophy,[94] Bohm and his collaborator Jeffrey Bub have gone out of their way to differentiate Bohr's approach from that of Heisenberg and von Neumann and to claim an affinity between the hidden variable approach and the former.[95] However, the only aspect of Bohr's philosophy with which they can agree is the indivisibility or wholeness of the atomic system and its environment.[96] They completely reject the use of classical concepts (the correspondence principle)[97] and ignore the principle of complementarity.[98] So there is really very little in common between them in spite of all the claims to the contrary.

5.6 Ernst Cassirer and Henry Margenau:

Many of the writers we have discussed have interpreted complementarity in a Kantian manner, but none so consciously and deliberately as Ernst Cassirer and Henry Margenau. In 1937 Cassirer published his <u>Determinismus und Indeterminismus in der modernen Physik</u>[99] in which he argued that causality is a permanent feature of physics because every experimental procedure must presuppose causality to begin with.[100] When new fields of physics are discovered the causality principle must always be reinterpreted in such a way that it retains its full validity.[101] In fact, Cassirer equated causality with objectivity since it is only by establishing causal patterns that man can distinguish objective reality from subjective experience.[102] If it turns out, as it does in quantum theory, that <u>individual events</u> do not obey strictly causal laws (dynamical causality) but that <u>patterns of events</u> do (statistical causality), then it is the patterns which must be regarded as basic rather than the events themselves.[103] Therefore, Cassirer rejects Bohr's correspondence principle - he called it "Ariadne's thread in the labyrinth of quantum theory"[104] - as a compromise between the old physics and the new because it retains the classical notion of causality and subjects it to severe restrictions (uncertainty and complementarity) rather than completely redefining it so as to avoid these restrictions and maintain its full validity.[105] The root of this difference between Cassirer and Bohr goes back to their different ideas of objectivity: for Cassirer it is basically recurrence or invariance which can be recognized by the individual whereas for Bohr it is basically unambiguous information which can be communicated to others.[106]

Margenau picks up where Cassirer left off: just as Cassirer identified patterns of events as the basic reality, so Margenau regards the wave-function as more real than space-time events because it obeys causal laws whereas the latter do not.[107] The remoteness and abstractness of the wave-function are no deterrent[108] since for Margenau physical reality can only be attributed to mental constructs which satisfy certain metaphysical criteria: permanence, stability and causality are among them, but concreteness is not.[109] Actually most physicists wouldn't even agree that the wave-function is permanent and stable since it is generally thought to collapse acausally during the measurement process in accordance with von Neumann's "projection postulate".[110] Of course, Margenau rejects the projection postulate because it destroys causality and objectivity,[111] but then his whole argument becomes circular, viz. the wave-function is real because it obeys causality and it obeys causality because it is objectively real. Perhaps the reason this circularity does not disturb Margenau is that he regards permanence as an attribute of constructs depending on individual taste rather than a feature of reality (Margenau would not allow this distinction between constructs and reality) to be discovered by communal effort.[112]

Margenau's treatment of complementarity is a natural consequence of his idealistic metaphysic.[113] In his earlier writings (during the late forties and fifties) he interpreted complementarity as a relation between physical reality (valid constructs like the wave-function) and historical reality (sense data like space-time events)[114] as Heisenberg and Planck also did.[115] But whereas Heisenberg and Planck regarded physical reality to be noumenal and unobservable and hence independent of man,[116] Margenau regards it as a mental construction subject to human manipulation.[117] Based on this (mis-) interpretation of complementarity, Margenau's criticism is that Bohr has asked science to resign itself to an "eternal dilemma", an "unbridgeable chasm" between objective reality (the "physical" wave-function) and subjective appearances ("historical" space-time events).[118] Margenau's solution, then is to "cut off one horn of the complementarity dilemma" by taking the wave-function as the only valid description of physical reality.[119]

In his later writings (during the sixties) Margenau apparently realized that Bohr's complementarity was really a relationship between wave and particle modes, and he changed his line of criticism accordingly. The idea of an alternation between two modes, he said, does violence to one's monistic intuition, and since permanence and stability are metaphysical requirements (at least for Margenau) complementarity must be an anti-metaphysical, positivistic concept![120]

Reality must be invariant hence an electron must ultimately be neither a wave nor a particle (nor a "wavicle").[121] In fact, an individual instance of an electron is not physically real at all: only the ensemble of electrons which obeys statistical causality has physical reality.[122] Bohr's concept of complementarity, Margenau concluded, could only appeal to philosophers and theologians who go in for myths, allegories and paradoxes![123]

However, the issue here is neither one of metaphysics and positivism nor one of metaphysics and mythology, but rather of two equally metaphysical positions: Margenau's position is essentially Platonic or Parmenidean, as he states,[124] whereas Bohr's is basically Heraclitean.[125] The real issue is whether change is real or only apparent and hence whether reality is invariant or inherently dynamic.

5.7 Alfred Landé, Karl Popper and Mario Bunge:

Few people have misunderstood complementarity more thoroughly and persistently than Alfred Landé, Karl Popper and Mario Bunge. I group them together because they share a formalist position, with a strong preference for formal axiomatic systems over the use of intuitive physical models,[126] and a commitment to the complete reduction of matter-wave phenomena to a purely corpuscular interpretation.[127]

Landé was originally a faithful adherent of the Copenhagen interpretation, but during the early fifties he became dissatisfied with the wave-particle "dualism", and he has been its most relentless critic ever since.[128] In his earlier writings[129] he used the word "complementarity" rather than "dualism", but the concept is the same: it is not complementarity in Bohr's sense. It is similar to Born's concept of "duality"[130] and is what we have been calling equivalence or supplementarity.[131] Somehow the confusion between these concepts must be clarified if there is to be any progress in the debate about complementarity.[132]

Karl Popper's criticisms of the Copenhagen school have been largely directed against the views of Heisenberg,[133] but he has also commented briefly on Bohr. His principal complaint against Bohr is the vagueness and difficulty of his explanations of complementarity.[134] In fact, Popper was so perplexed by Bohr's writings that he wasn't sure whether to identify Bohr's interpretation with Heisenberg's or not![135] He was also disturbed by the "renunciation" of a unitary picture inherent in complementarity,[136] and he charged that Bohr's principle was sterile and that it had produced nothing more than pointless philosophical discussions.[137] In fact, complementarity has not inspired much new research in physics, largely because there has been so much confusion about its true meaning, but it has been fruitful in the area of biology.[138] Hopefully it will become fruitful in other fields as well as its interpretation is gradually clarified.

Mario Bunge published two important articles in the years 1955-1956 which were strongly critical of the Copenhagen view and of complementarity, in particular,[139] and he has periodically renewed the attack ever since. He is one of the few persons ever to have recognized Bohr's use of classical concepts as a form of analogical thinking,[140] and he rejects it as such.[141] Other than that, his criticisms are mostly based on gross misunderstandings: for instance, he criticizes Bohr for basing his arguments on the limits of measurement rather than definition;[142] he misinterprets Bohr's rejection of the "thing-in-itself" as a form of idealism rather than a relational view of attributes[143] (a view incidentally which Bunge shares!)[144]; and he rejects the idea of complementarity between thermodynamic macrostates and atomic microstates because these represent different levels of matter and hence are not completely symmetrical![145] In fact, Bunge has many of the qualities of a good complementarist. Only his rejection of analogical thinking stands in his way.

5.8 Paul K. Feyerabend:

No one has struggled with Bohr's ideas more valiantly than Paul Feyerabend.[146] He is virtually the only critic who has really studied Bohr's writings and endeavoured to improve his understanding of the philosophy he was evaluating. His various papers from 1957 onwards show an ever-increasing appreciation of Bohr's intentions, and they are the only writings I could recommend as an introduction to Bohr's work.

Feyerabend's strong points are his clear distinction between Bohr and other members of the "Copenhagen school",[147] his recognition that Bohr was concerned with physical principles more than mathematical formalisms,[148] his appreciation of Bohr's relational view of attributes,[149] his gradual realization that Bohr's position was basically realist and objective,[150] and his recognition of the incommensurability of classical and quantum-mechanical concepts.[151] However, Feyerabend still shows no signs of understanding the role of classical concepts in Bohr's philosophy. His persistent efforts in this direction and the fantastic explanations he develops suggest that he is still not satisfied on this point,[152] but his cyclical view of the history of science makes it unlikely that Bohr's position will ever really make sense to him.[153] Moreover, Feyerabend has confined his interest to Bohr's general philosophy and has not yet examined the logic of complementarity itself or its various applications outside the field of atomic physics.[154] Nonetheless, he has performed an invaluable service in giving us the first coherent exposition of Bohr's ideas.

On this positive note we close our discussion of Bohr's critics. Hopefully, new and more searching criticisms will emerge with time as the concept of complementarity itself is clarified.

Footnotes: Chapter 5.

1. "Über das Gestez der Energieverteilung im Normalspektrum", Ann.Phys. 4, 1901, pp.553-563.

2. See e.g. A.Einstein, Ideas and Opinions, pp.226-227.

3. Where Is Science Going?, London, 1933, pp.93-94, The Philosophy of Physics, London, 1936, p.77, The Universe in the Light of Modern Physics, London, 1937, pp.8-10,14-15, Scientific Autobiography and Other Papers, London, 1950, pp.100-105. In all of these references Planck speaks of a metaphysical "real world" which stands "behind" the phenomenological world of sense data, but on pp.101-102 of the last reference he explains that "the word, behind, must not be interpreted in an external or spatial sense. "Instead of 'behind', we could just as well say, 'in' or 'within'. Metaphysical reality does not stand spatially behind what is given in experience, but lies fully within it." This is a helpful distinction, but unfortuneately Planck does not maintain it consistently. A few pages later (p.105) he speaks again of the unbridgeable chasm between the world of phenomenology and the real world.

4. Where Is Science Going?, pp.86-87,92,94-95, The Universe, etc., pp.9-11; cf. K.Popper, Conjectures and Refutations, ch.3, and above, ch.1, fn.93.

5. Where Is Science Going?, pp.64,100,140,157-158, The Philosophy of Physics, pp.41,53,76-77, The Universe, etc., pp.48,58-59, Scientific Autobiography, etc., p.149. Contrast Bohr's use of causality as a classical concept, ch. 1, fn.82 above.

6. In The Universe, etc., p.38, Planck mentions the "complementariness" between the uncertainties of position and momentum but does not develop the idea.

7. The Philosophy of Physics, pp.61-62, The Universe, etc., pp.54-55, Scientific Autobiography, etc., pp.130-131, 136-138.

8. See above, ch.4.3.

9. The Universe, etc., pp.54-55.

10. A Survey of Physics, London, 1925, p.107, Where Is Science Going?, pp.102-104,163-165, The Philosophy of Physics, p.32, The Universe, etc., pp.85-109, Scientific Autobiography, etc., pp.72-75.

11. The Universe, etc., p.105, Scientific Autobiography, etc., pp.72-75.

12. Scientific Autobiography, etc., p.75; cf. The Philosophy of Physics, p.32. This passage is quoted by C.A.Coulson as an example of complementarity: Science and Christian Belief, p.96; see below, ch.6.2.

13. _Scientific Autobiography, etc._, p.109.

14. _ibid_, pp.67-69.

15. _ibid_, p.59. _N.B._ The last two references come from an essay written in 1946 ("Phantom Problems in Science", in _Scientific Autobiography, etc._, pp.52-79) and may reflect an awareness of Bohr's writings. But the treatment of free will is much earlier and may well have influenced Bohr in the first place.

16. "Therefore, it will do no harm to say that the physical and the mental are in no way different from each other. They are the selfsame processes, only viewed from two diametrically opposite directions." _Scientific Autobiography, etc._, p.69; cf. ch.2.3 above. A recent article by G.G.Globus ("Unexpected Symmetries in the 'World Knot'", _Science_ 180, 1973, pp.1129-1136) treats the mind-body problem (the 'world knot') in exactly the same manner. According to Globus, whether a psycho-physical event is observed as a 'pure', mental event or a physical change in the nervous system depends on whether it is observed from the 'proximal' or the 'distal' side of the 'transformation boundary' between nervous system and physical environment. Accordingly the two 'perspectives' are mutually exclusive only for a given observer, but not in absolute terms.

17. See above, ch.2.8.

18. See above, pp.13ff.

19. See above, pp.7f.

20. "Of the 'orthodox' quantum theoreticians whose position I know, Niels Bohr's seems to me to come nearest to doing justice to the problem." "Reply to Critics", in P.A.Schilpp, ed., _op.cit._, p.681.

21. "From these meager remarks one will see that to me it must seem a mistake to permit theoretical description to be directly dependent upon acts of empirical assertions, as it seems to me to be intended (for example) in Bohr's principle of complementarity, the sharp formulation of which, moreover, I have been unable to achieve despite much effort which I have expended on it. From my point of view (such) statements or measurements can occur only as special instances, viz., parts, of physical description, to which I cannot ascribe any exceptional position above the rest." _ibid_, p.674; cf. Einstein's letter to Schrödinger (9 Aug. 1939) in K.Przibram, ed., _Letters on Wave Mechanics_, New York, 1967, p.36.

22. _Ideas and Opinions_, p.334; cf. Pauli's letters to Born (1954) in which he characterizes Einstein's position as "realistic" rather than "deterministic"; see _The Born-Einstein Letters_, pp.218,221. On complementarity and indeterminism, see above, pp.64f.

23. *Ideas and Opinions*, pp.275,318, *The Born-Einstein Letters*, p.158.

24. *The World As I See It*, pp.193-204.

25. *The Born-Einstein Letters*, p.171.

26. *ibid*, pp.158,164,170,218.

27. cf. ch.1.5 above.

28. See p.15 above.

29. "Are There Quantum Jumps?", *B.J.P.S.* 3, 1952, p.120, "What Is Matter?", *Sci.Am.* 189 (No.3), 1953, p.56, *My View of the World*, Cambridge, 1964, p.43. Concerning Einstein's influence on Schrödinger see K.Przibram, ed., *op.cit.*, p.26; E.Schrödinger, "Die genenwärtige Situation in der Quantenmechanik", *Naturwis.* 23, 1935, p.845; and V.V.Raman and P.Forman, "Why Was It Schrödinger Who Developed de Broglie's Ideas?", in R.McCormach, ed., *Historical Studies in the Physical Sciences*, *Vol.1*, Philadelphia, 1969, pp.291-314.

30. "Quantisierung als Eigenwertproblem", *Ann.Phys.* 79, 1926, p.375; "The Meaning of Wave Mechanics", in A.George, ed., *op.cit.*, p.18.

31. The conversation is recalled by W.Heisenberg in *Physics and Beyond*, pp.73-76.

32. W.T.Scott, *Erwin Schrödinger: An Introduction to His Writings*, pp.83-87, esp. p.86.

33. *Science and the Human Temperament*, London, 1935, p.154, "What Is Matter?", pp.54-55, and *Was Ist Ein Naturgesetz?*, Munich/Vienna, 1962, pp.101,112-114.

34. See ch.2.6 above for a description of one such experiment.

35. e.g. "What Is An Elementary Particle?", *Endeavour* 9, 1950, pp.112,115-116, and "Are There Quantum Jumps?", p.240.

36. "If Heisenberg's assertion is correct, and it it appears at first sight to make gaps in our picture of the world which cannot be filled, then the obvious thing to do is to eliminate the regions which refuse to be filled with thought; in other words to form a view of the world which does not contain those regions at all." *Science and the Human Temperament*, pp.131-132; cf. *Science and Humanism*, Cambridge, 1951, pp.40-41,49-50.

37. *My View of the World*, pp.18-22 ("The Vedantic Vision"), p.41.

38. de Broglie has frequently recounted these stages of development: "L'Interprétation de la Mécanique Ondulatoire", *J.Phys.Rad.* 20, 1959, p.963, *Non-Linear Wave Mechanics*,

Amsterdam, 1960, Preface and pp.89-93, New Perspectives in Physics, Preface and pp.83-96, The Current Interpretation of Wave Mechanics, Amsterdam, 1964, Preface. When criticized for being fickle, he once replied with a quotation from Voltaire, "L'homme stupide est celui qui ne change pas". La Physique Quantique Restera-t-elle Indeterministe?, Paris, 1953, p.22.

39. See ch.2, fn.61 above.

40. "La Mécanique Ondulatoire et la Structure Atomique de la Matière et du Rayonnement", J.Phys.Rad., Series 6, 8, 1927, p.225, Non-Linear Wave Mechanics, pp.3,89, and "The Interpretation of Wave Mechanics", Foundations of Physics 1, 1970, p.5.

41. "La Mécanique Ondulatoire, etc.", pp.225-226, An Introduction to the Study of Wave Mechanics, London, 1930, p. 6, and The Current Interpretation of Wave Mechanics, pp.9,37-41.

42. An Introduction to the Study of Wave Mechanics, pp.6-7, 120-121, "L'Interprétation de la Mécanique Ondulatoire a l'Aide d'Ondes à Régions Singulières", in Scientific Papers Presented to Max Born, Edinburgh, 1953, p.22, and New Perspectives in Physics, pp.96,111,176.

43. See Matter and Light, pp.255,278, The Revolution in Physics, London, 1954, pp.18-19,217-218, and Physics and Microphysics, London, 1955, pp.112,138-139,236,241.

44. New Perspectives in Physics, p.98.

45. ibid, p.vi; cf. p.105.

46. The Current Interpretation of Wave Mechanics, p.68.

47. An Introduction to the Study of Wave Mechanics, p.145.

48. ibid, pp.8-9.

49. "Individualité et Interaction dans le Monde Physique", pp.356-360, Matter and Light, p.279, "Sur la Complémentarité des Idées d'Individu et de Système", Dialectica 2, 1948, pp.325-329, The Revolution in Physics, p.281, and Physics and Microphysics, p.135; cf. P.Destouches-Février, "Relations d'Incertitude Liées à la Complémentarité Corpuscules-Système de Louis de Broglie", Comptes Rendus 226, 1948, pp.468-470, and "Manifestations et Sens de la Notion de Complémentarité", Dialectica 2, 1948, pp.397-399.

50. Matter and Light, p.279, and Physics and Microphysics, p.135.

51. "Individualité et Interaction, etc.", pp.357-358.

52. ibid, p.357, Matter and Light, pp.279-280, and "Sur la Complémentarité, etc.", p.328.

53. See above, pp.132,152.

54. See above, pp.94,149,157f.

55. See above, p.62.

56. de Broglie concludes his 1948 paper on complementarity with the words, "À cet égard comme à bien d'autres, la profonde conception nouvelle introduite par Bohr apparaît comme susceptible de nombreuses applications." ("Sur la Complémentarité, etc.", p.329). Three years later he changed his mind and rejected complementarity altogether. Compare his previous enthusiasm with the following statement: "The idea of complementarity, although a bit elusive is an interesting one. Attempts have been made to apply it in various fields - a procedure that is not always entirely safe." (Non-Linear Wave Mechanics, p.63).

57. New Perspectives in Physics, p.vi.

58. Bohm sent him a preprint of his first paper on "hidden variables" ("A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables", Phys.Rev. 85, 1952, pp.166-193, esp. p.167) in the spring of 1951; see New Perspectives in Physics, p.83.

59. Vigier pointed out the similarity between de Broglie's "theory of the double solution" and Einstein's ideas about particles as singularities in a universal field; see J.P.Vigier, "Introduction Géométrique de l'Onde Pilote en Théorie Unitaire Affine", Comptes Rendus 233, 1951, pp.1010-1012; and L.de Broglie, "Remarque sur la Note Précédente de M.Vigier", ibid, pp.1012-1013, and "L'Interpretation de la Mécanique Ondulatoire, etc.", p.32.

60. Non-Linear Wave Mechanics, pp.vi,95,291-292, New Perspectives in Physics, pp.94,142-144,148, The Current Interpretation of Wave Mechanics, pp.36-37,43-44. For Einstein's views see e.g. "Autobiographical Notes", in P.A. Schilpp, ed., op.cit., pp.77,87,89. Incidentally, Einstein was not impressed by the theories of either Bohm or de Broglie; see The Born-Einstein Letters, p.192.

61. Non-Linear Wave Mechanics, p.290.

62. ibid, pp.223-231, New Perspectives in Physics, pp.116-120. The linear solution is similar to Schrödinger's wave-function except that it is not normalized and it never collapses; see Non-Linear Wave Mechanics, p.266, and The Current Interpretation of Wave Mechanics, pp.47-48.

63. "L'Interpretation de la Mécanique Ondulatoire", pp.965, 975-976, Non-Linear Wave Mechanics, p.287, The Current Interpretation of Wave Mechanics, pp.viii,42-43, "The

Reinterpretation of Wave Mechanics", p.14. This idea was also inspired by the work of Bohm and Vigier ("Model of the Causal Interpretation of Quantum Theory in Terms of a Fluid with Irregular Fluctuations", Phys.Rev., 96, 1954, pp.208-216).

64. "The Reinterpretation of Wave Mechanics", p.14.

65. "L'Interprétation de la Mécanique Ondulatoire", p.965.

66. Non-Linear Wave Mechanics, p.62.

67. The Current Interpretation of Wave Mechanics, pp.7-8.

68. Non-Linear Wave Mechanics, p.63.

69. Quantum Theory, New York, 1951.

70. ibid, p.iii.

71. ibid, pp.iv,140.

72. ibid, pp.iv,139,157-161.

73. ibid, pp.133-136.

74. ibid, pp.133,136-139.

75. ibid, p.610.

76. ibid, p.162.

77. ibid, pp.624-628; cf. von Weizsäcker's concept of "circular complementarity", ch.4.4 above.

78. See pp.168f above.

79. loc.cit., pp.29,101,114-115,139,171,622-623.

80. ibid, p.29.

81. ibid, pp.29,115,623.

82. "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables", Phys.Rev. 85, 1952, p.168.

83. See p.91 above.

84. Bohm's hierarchical treatment of physics is amplified in Causality and Chance in Modern Physics, London, 1957, pp.51,121,139,145-146,155,166. Here he allows each level an autonomy and stability of its own in keeping with Bohr's basic ideas.

85. See D.Bohm, "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables", Phys.Rev. 85, 1952, pp.166-193, "Proof That Probability Density Approaches $/\Psi/^2$ in Causal Interpretation of the Quantum

Theory", *Phys.Rev.* 89, 1953, pp.458-466, "Comments on an Article of Takabayasi Concerning the Formulation of Quantum Mechanics with Classical Pictures", *Prog.Th. Phys.* 9, 1953, pp.273-287; D.Bohm and J.P.Vigier, "Model of the Causal Interpretation of Quantum Theory in Terms of a Fluid with Irregular Fluctuations", *Phys. Rev.* 96, 1954, pp.208-216; D.Bohm, "A Proposed Explanation of Quantum Theory in Terms of Hidden Variables at a Sub-Quantum-Mechanical Level", in S.Körner, ed., *op. cit.*, pp.33-40; J.P.Vigier, "The Concept of Probability in the Frame of the Probabilistic and the Causal Interpretation of Quantum Mechanics", *ibid*, pp.71-77.

86. "A Suggested Interpretation, etc.", pp.166,168, "Proof, etc.", pp.465,466, "Comments, etc.", p.282.

87. *Causality and Chance in Modern Physics*, pp.93,98,111-112, 117,138.

88. "Comments, etc.", p.282.

89. *ibid*, p.284 ("Even if there really were no cause, no error could come from the assumption that there was one. All that would happen would be that our efforts to find the cause would not be successful. But if, as is much more likely, there really is a cause, and we assume there is not, then we may be lead to overlook important new factors that are needed in the theory".).

90. "A Suggested Interpretation, etc.", p.180.

91. *ibid*; cf. "Comments, etc.", pp.275-276.

92. See above, pp.10f. Even Heisenberg in his *Physical Principles of the Quantum Theory* (ch.2) based his arguments on theory and only cited thought experiments as illustrations.

93. "A Suggested Interpretation, etc.", "Comments, etc.", p.279; and D.Bohm and J.Bub, "A Proposed Solution of the Measurement Problem in Quantum Mechanics by a Hidden Variable Theory", *Rev.Mod.Phys.* 38, 1966, pp.458,469.

94. "Classical and Non-Classical Concepts in the Quantum Theory: An Answer to Heisenberg's *Physics and Philosophy*", *B.J.P.S.* 12, 1962, pp.265-280.

95. J.Bub, "Hidden Variables and the Copenhagen Interpretation - A Reconciliation", *B.J.P.S.* 19, 1968, pp.185-210; and D.Bohm, "On Bohr's Views Concerning the Quantum Theory", in T.Bastin, ed., *op.cit.*, pp.33-40, and "On the Role of Hidden Variables in the Fundamental Structure of Physics", *ibid*, pp.95-116. Note: since 1969 Bub has taken a completely different tack; see his "Under the Spell of Bohr", *B.J.P.S.* 24, 1973, pp.78-90.

96. D.Bohm, "Classical and Non-Classical Concepts, etc.", pp.266,277; cf. ch.1, fn.122 above.

97. D.Bohm, loc.cit., pp.273-275, "On Bohr's Views, etc.", p.40; and J.Bub, "Hidden Variables, etc.", pp.186,190-191,206.

98. D.Bohm, B.J.Hiley, and A.E.G.Stuart, "On a New Mode of Description in Physics", International Journal of Theoretical Physics 3, 1970, pp.172-173.

99. E.T., Determinism and Indeterminism in Modern Physics, New Haven, 1956. Margenau wrote the preface to the English version.

100. ibid, pp.119,123.

101. ibid, p.127.

102. ibid, pp.119,132.

103. ibid, p.119.

104. ibid, p.111.

105. "We certainly do not have a satisfactory situation when definite concepts are accepted for the time being only to be subsequently corrected through restrictions to certain conditions and thus alone really justified and certified in their application." ibid, pp.112-113.

106. See above, ch.1.3.

107. "Reality in Quantum Mechanics", p.300, The Nature of Physical Reality, pp.414,418-419, and "Preface" to E. Cassirer, op.cit., pp.xviii,xix.

108. "Reality in Quantum Mechanics", pp.300-301, and The Nature of Physical Reality, p.419.

109. The Nature of Physical Reality, pp.1-10,81,100,292.

110. See above, ch.4, fn.115.

111. Margenau has written many papers criticizing the projection postulate. The most recent are: "Measurements and Quantum States", Phil.Sci. 30, 1963, pp.1-16,138-157, and "Measurements in Quantum Mechanics", Annals of Physics 23, 1963, pp.469-484.

112. "When a tree is seen, the tree is the construct; the unitary experience of the tree is summed up in that way. The tree is permanent exactly to the extent which permanence has been invested as a rational element in the construct. There is not a tree and my construct of it, nor a wavelength and my construct of it." "Reality in Quantum Mechanics", pp.293-294; cf. The Nature of Physical Reality, p.70.

113. Margenau sometimes speaks of his position as idealist and

sometimes claims to reject both realism and idealism; see "Reality in Quantum Mechanics", p.287, The Nature of Physical Reality, pp.3,71,98.

114. "Reality in Quantum Mechanics", p.299, The Nature of Physical Reality, p.421, "Advantages and Disadvantages of Various Interpretations of the Quantum Theory", p.9, and "Preface" to E.Cassirer, op.cit., p.xx; cf. ch.2.2 above.

115. See above, chs.4.3 and 5.1.

116. Planck, for instance, distinguishes between the real world, the world of the senses and the world of physics (The Universe in the Light of Modern Physics, pp.9-11), whereas Margenau identifies the first and third of these. In Margenau's terminology, physical reality is on man's side of the P (perception)-plane for Margenau and it is on the other (noumenal) side for Planck and Heisenberg.

117. "...I am perfectly willing to admit that reality does change as discovery proceeds. I can see nothing basically wrong with a real world which undergoes modifications with the flux of experience." The Nature of Physical Reality, p.295.

118. ibid, pp.422,426, "Advantages and Disadvantages, etc.", p.9. As we have seen there is no such dichotomy in Bohr's philosophy; see ch.1.5 above.

119. "Advantages and Disadvantages, etc.", p.10.

120. "Admittedly, this view does violence to one's monistic intuition, but in an age of positivism one may have to assuage one's metaphysical conscience by relying on facts and logic alone, yielding the natural desire for unity of explanation, the philosophic instinct which abhors a fundamental ambiguity in the realm of nature's ultimate constituents." Open Vistas, p.156.

121. The Nature of Physical Reality, p.321, Open Vistas, p. 161, "The Philosophical Legacy of Contemporary Quantum Theory", in R.G.Colodny, ed., Mind and Cosmos, Pittsburgh, 1966, p.351.

122. The Nature of Physical Reality, pp.375,418, Open Vistas, p.144.

123. "The appeal [of complementarity] is to the deeper concerns of our being, somewhat reminiscent of a modern trend that the knowledge of divinity is possible only through myths, allegories, and paradoxes." Open Vistas, p.162; cf. "The Philosophical Legacy, etc.", p.349.

124. "Like Parmenides and Plato we feel dissatisfied with the messages delivered to us by external perceptions, for

these messages are peculiarly incoherent, full of surprises, and cryptic in their meaning. The mind prefers to behold conditions that expose themselves to leisurely and careful view; to it the changeable external world is a perpetual offense. Thus arises the suggestion that the sensory world may, after all, not be wholly real, for it violates the cherished postulate of permanence." The Nature of Physical Reality, p.3.

125. See above, pp.65-66.

126. See above, pp.17-18 and A.Landé, Quantum Mechanics, pp. 7-8, "New Foundations for Quantum Physics", Physics Today 20 (No.2), 1967, pp.55-58; K.Popper, "Quantum Mechanics without 'The Observer'", in M.Bunge, ed., Quantum Theory and Reality, Berlin, 1967, p.14; and M. Bunge, Intuition and Science, p.107, and "Analogy in Quantum Theory: From Insight to Nonsense", pp.280-282.

127. A.Landé, Foundations of Quantum Theory, New Haven, 1955, pp.75-76, From Dualism to Unity in Quantum Physics, Cambridge, 1960, pp.97,100, and New Foundations of Quantum Mechanics, pp.x,4,7,8,20,107,109-110,113,117,118,140; K.Popper, "The Propensity Interpretation of the Calculus of Probability", in S.Körner, ed., op.cit., p.68, and "Quantum Mechanics without 'The Observer'", pp.21,39-40; and M.Bunge, Foundations of Physics, Berlin, 1967, p. 235, and "Analogy in Quantum Theory, etc.", p.268.

128. Foundations of Quantum Theory (New Haven, 1955) is the first publication in which Landé clearly criticized "duality". For a summary of Landé's views see the "Introduction" to W.Yourgrau and A.van der Merwe, eds., Perspectives in Quantum Theory: Essays in Honor of Alfred Landé, Cambridge, Mass., 1971.

129. Principles of Quantum Mechanics, Cambridge, 1937, and Quantum Mechanics, London, 1951.

130. See above, pp.143-145.

131. See above, ch.2.5, esp. fn.60.

132. It is most discouraging to see that Landé's most recent diatribe against "duality" is based on the same misunderstanding: "The Decline and Fall of Quantum Dualism", Phil.Sci. 38, 1971, pp.221-223.

133. The Logic of Scientific Discovery, pp.221,232-234,452-453.

134. "Discussion" in S.Körner, ed., op.cit., p.89, The Logic of Scientific Discovery, pp.454,456, and "The Argument of Einstein, Podolsky, and Rosen", in W.Yourgrau and A. van der Merwe, eds., op.cit., p.185.

135. The Logic of Scientific Discovery, pp.453,454,456.

136. ibid, p.454, and Conjectures and Refutations, p.100.

137. Conjectures and Refutations, p.101.

138. Especially in the work of P.Jordan, W.M.Elsasser, and M.Delbrück.

139. "Strife About Complementarity", B.J.P.S. 6, 1955, pp. 1-12,141-154, and "Survey of the Interpretations of Quantum Mechanics", Am.J.Phys. 24, 1956, pp.272-286 (both reprinted in Metascientific Queries, Springfield, Illinois, 1959).

140. "Analogy in Quantum Theory", p.273; see above, pp.16-18.

141. See ch.1, fn.114.

142. "Strife About Complementarity", pp.3,148-149, "Survey of the Interpretations of Quantum Mechanics", p.281.

143. "Strife About Complementarity", p.6.

144. "This [fact that there are no isolated systems in quantum mechanics], far from meaning that an observer must always be taken for granted, only means that other material systems, macroscopic ones, are always in interaction with the microscopic system under consideration." "Survey of the Interpretations of Quantum Mechanics", p.275; cf. p.281, and "Analogy in Quantum Theory, etc.", p.273. See above, pp.24f,136f.

145. "Strife About Complementarity", p.148. See above, chs. 2.10 and 3.1.

146. See above, ch.1, fns.5,49,50,74,85,86,87.

147. "Complementarity I", p.80, "Problems of Microphysics" pp.201,221,237,250,259,271,273-274, and "On a Recent Critique of Complementarity II", pp.94-97.

148. "Complementarity I", p.96, and "On a Recent Critique of Complementarity II", pp.82-88.

149. "Niels Bohr's Interpretation of the Quantum Theory", p. 372, "Problems of Microphysics", pp.217,219, and "On a Recent Critique of Complementarity I", p.311; cf. Hooker's criticism of Feyerabend's interpretation of Bohr: C.A.Hooker, loc.cit., pp.150-152.

150. "Problems of Microphysics", pp.202,220,259, and "On a Recent Critique of Complementarity I", p.322 and "II", pp.96-97.

151. "On a Recent Critique of Complementarity I", pp.315-320.

152. "An Attempt at a Realistic Interpretation of Experience", pp.152-153, "Complementarity I", pp.84-88, "Niels Bohr's

Interpretation of the Quantum Theory", pp.387-389, "Problems of Microphysics", pp.228,231.

153. See ch.1, fns.85,86.

154. Feyerabend rejects these "generalizations" of complementarity as "very weak and mostly invalid", but he doesn't really consider them seriously.

Part II

The Logic of Complementarity in Theology

Chapter 6

Possible Theological Uses of Complementarity

> "The appropriate answer to 'Are theological paradoxes like the wave-particle duality?' is not 'yes' or 'no' but a full account of the ways in which they are like and unlike." W.H.Austin, Waves, Particles, and Paradoxes, p.97.

Niels Bohr once recommended that theologians make more use of the principle of complementarity in their work,[1] and we intend to follow him up on this suggestion. First we should review the efforts of other theologians in this direction and get some idea of the possible applications to be considered. Bohr himself suggested applications to (a) creaturely freedom and divine sovereignty, and (b) the immanence and transcendence of God with respect to time.[2] These will come up again in this chapter, and there will be other suggested applications as well.

6.1 Günter Howe:

One of the regular participants in the "Göttingen circle" of scientists and theologians was Günter Howe. Howe was trained as a physicist himself, but he also studied Barth's Kirkliche Dogmatik and contributed an article to the Festschrift dedicated to Barth on his seventieth birthday in which he drew parallels between Barth's theology and modern physics.[3]

There are two important points with respect to our thesis which Howe brings out in his writings. First, he stresses that modern (quantum) physics leads beyond the classical antithesis of materialism (mechanism) and idealism.[4] Citing Heisenberg and von Weizsäcker on the "breakdown of objectivity" in modern physics, he wisely avoids using the term "subjectivity" (Subjectivismus) and refers instead to "non-objectifiability" (Nichtobjectivierbarkeit), i.e. a transcendence of both objectivity and subjectivity.[5] The use of a term like "non-objectifiability" (cf. Athanasius's dianoia in contrast to the epinoia of the Arians)[6] would help to prevent confusion since the dependence of the atomic object on the observing "subject" in the act of measurement is no different from its dependence on its macroscopic environment in any other situation. As Bohr himself stressed, it is the complete specification of the experimental conditions that is important, not the presence or absence of a conscious "subject".[7] Howe has helped to clarify this point.

Secondly, Howe follows von Weizsäcker in interpreting Bohr's principle of complementarity in a "circular" rather than "parallel" fashion.[8] He does this in order to strengthen the analogy to Barth's idea of the veiling and unveiling of God which involves a "circle of knowledge" rather than a strict parallelism. As we have pointed out before, this approach confuses the "pointing relation" of complementarity with the cyclical relation of correspondence.[9] The relationship between God-revealed and God-concealed is one of dependence and pointing beyond, not of epistemological circularity. We shall return to this issue in chapter nine.

6.2 C.A.Coulson and D.M.Mackay:

The two men primarily responsible for popularizing the idea of complementarity in Christian thought have been Charles A. Coulson and Donald M. Mackay. Both are trained in mathematics and physics and have a keen interest in the issues of modern philosophy. Coulson's writings are a good example of the theological difficulties one can get into by using the concept of complementarity carelessly. His "complementarity" is roughly what we have called orthogonality or modality - complementary aspects are different views or projections of an invariant reality.[10] Hence wave and particle are simply two alternate interpretations of electrons or of light; they do not reflect any change in the object itself.[11] Similarly, final and effective causes represent alternate viewpoints in both physics and biology.[12] Coulson also follows Planck in regarding mind and matter or free will and determinism as the same reality viewed from within and without.[13] Finally, he sees science as a whole and religion as different ways of viewing the same reality whether it is called Nature of God.[14] Without qualification he quotes Alexander Pope's famous lines:

> All are but parts of one stupendous whole,
> Whose body Nature is, and God the soul.

and speaks freely of the sacramentality of Nature as the body of Christ.[15] These misleading (though not entirely false!) ideas are avoided when complementarity is treated as a relation between distinct modes of being rather than aspects of an invariant object. We take this up again in chapter eight.

Mackay has repeatedly insisted that complementarity should be treated as a logical rather than a physical relation.[16] By this he means that complementarity arises whenever an object of many logical dimensions is described in terms of concepts that have fewer dimensions than the object itself.[17] Again, this is not complementarity in Bohr's sense but what we have called orthogonality. However, Mackay, unlike Coulson, allows for complementarity between conceptual or ontological levels as well as logical dimensions.[18] Here he has in mind relationships such as that between mental and physical or between sign and thing-signified.[19] This comesvery close to Bohr's concept of complementarity (e.g. between elementary particles and stable atoms) although Mackay denies this repeatedly. It certainly makes his treatment of the complementarity between the events of nature and the activity of God more suitable than Coulson's;[20] however, neither Mackay nor Coulson really examines the theological issues to see whether the concept of complementarity is entirely valid in this regard.

6.3 Ian G.Barbour:

In his classic text on science and religion, Ian Barbour has given us four helpful cautions about applying complementarity to fields outside atomic physics and to the field of theology in particular.[21] (1) He points out that such applications are necessarily <u>analogical</u> and not <u>inferential</u>, that is, the use of complementarity cannot automatically be transferred from one field to another; there must be independent grounds for its application in each field.

In other words, the appeal to complementarity must always be based on a prior knowledge of the issue at hand.[22] (2) Complementarity applies to different ways of analyzing a single entity under varying conditions, not to distinct entities. Hence it is improper to refer to science and religion as complementary in the strict sense unless one is willing to accept pantheism and deny the distinctness of God and nature. As Barbour puts it: "God and the world are different modes of being, not different modes of knowing a single being."[23] Evidently he is reacting to Coulson's defective use of complementarity here, but he has not noticed that Coulson's definition of complementarity is also defective and that if the definition is revised in keeping with Bohr's intention then the application can be made properly. If, as Barbour says, God and the world are different "modes of being", then they may be complementary provided that (a) an invariant, monistic being is not assumed and (b) God's own existence is recognized as being modal so that he may participate in complementarity with creation as its immanent creator and sustainer and also transcend creation as the one who dwells in eternity. More on this in chapter eight.

Finally Barbour warns us that (3) the acceptance of complementarity should not be taken as a veto against the search for a more unified description and (4) one ought not to abandon a critical realism just because the more naive form has finally broken down. All of this is good advice and is perfectly consistent with the philosophy of Bohr as we have understood it.

6.4 William H. Austin:

The most thorough work to date on the theological uses of complementarity is W.H. Austin's Waves, Particles, and Paradoxes.[24] Austin first tries to define complementarity, and then he examines possible applications to the "Christological paradox", i.e. the dual nature of Christ, and the love and justice of God. The principal difficulty with his definition is that he compromises the strict exclusiveness of complementary models in order to allow them to be intermixed.[25] He also ignores Bohr's analogical use of classical concepts in the correspondence principle.[26] When he examines the Christological paradox these omissions lead him to trouble: he begins by considering the models of Christ as God and Christ as man, but concludes that complementarity won't work with these two models because (a) the ideas of God and man cannot be "mixed" in Christian theology and (b) they are revised and improved through our understanding of the incarnation while there is (according to Austin) no significant change in the (classical) concepts of wave and particle in quantum physics.[27] Therefore, he discards the models of 'God' and 'man' and chooses instead to work with the models of 'Logos' and 'Messiah' which are supposed to represent the Alexandrian and Antiochene strands of Christology, respectively. However, the relation between these alleged strands in the history of religion is one of coexistence and interaction, not one of complementarity in Bohr's sense. Therefore, further consideration should be given to Austin's first suggestion of complementarity between the human and divine natures of Christ, and we shall take this up in chapter ten.

For the "paradox" of the love and justice of God Austin suggests the models of 'merciful Father' and 'just Judge'. However, he recognizes that these concepts cannot be strictly separated, that they are not opposed in Scripture, and that any apparent antithesis applies only to religious experience and cannot be maintained in systematic theology.[28] Clearly, there is no point in pursuing this possibility any further.

6.5 Complementarity as the Ontological Correlate of Revelation:

Thus far we have three possible applications of complementarity to consider in the field of theology: (a) the relationship between the (immanent) Creator and his creation, (b) the transcendence and immanence of God (with respect to time), and (c) the divinity and humanity of Christ. We shall examine each of these possibilities in turn, but first we ought to consider their <u>group characteristics</u> in order to decide whether there are other possible applications belonging to the same group (the problem of homology).[29] Secondly, we should also investigate the possibility that the members of this group are related to each other hierarchically as are the members of the complementarity group in science.[30] Finally, we should examine the progressive adaptation of complementarity from one end of this hierarchy to the other.[31] The many ramifications of these problems will occupy our attention throughout the remainder of this thesis. At this point we need only sketch an impressionistic outline and give a preliminary, heuristic consideration to the underlying principles. Therefore, we shall make use of the more intuitive concept of complementarity developed in chapter one and leave the detailed points of definition of chapter two for later verification.

The most striking feature of the three suggested applications of complementarity is their common "revelational" structure.[32] In each case there are two terms which might be called modes or poles: they are (polar) modes in that they cannot be separated or treated independently, and they are (modal) poles in that they cannot fused or reduced to a common third term. The relationship between these polar modes (or modal poles) is twofold: the first gives rise to the second chronologically or is prior to the second ontologically (e.g. "God created the heavens and the earth"), and the second always depends on the first and points back to the first as its proper source or ground (e.g. "the heavens declare the glory of God").

Now there are at least three other relations in theology which share the revelational structure of the three we have considered: (a) First, within the triune nature of God, there are the relations of Father to Son (generation and glorification), of Father to Holy Spirit ("spiration" and glorification), and possibly (depending on the filioque) of Son to Spirit. (b) Secondly, there is a universal relationship between "heaven" and "earth" as the respective abodes of God and man (e.g. "heaven is thy throne and earth is thy footstool"). It is generally understood (Russian astronauts notwithstanding) that heaven is not another place in the universe, but rather another pole or mode of the universe to which earthly events may direct our attention.[33] Hence, the somewhat unpopular topics of theophany and the doctrine of angels would come under this heading. (c) Finally, there is a more particular relationship between heaven and earth or between God and man in the doctrines of the church (the body of Christ), the word (the word of God and the word of man), and the sacraments (act of God and act of man). All of these relationships are inherently revelational and hence they should be considered together with the first three.

The principal question, therefore, is how this dual relationship of giving rise and pointing back is related to Bohr's concept of complementarity. Bohr's basic insight was that an object (e.g. the universe as a whole) may exist in one of two modes depending on whether it is analyzed in terms of its structure or applied and allowed to function in accordance with its design or purpose. At the level of theology, of course, this purpose would be revelational. Thus, creation as a whole is designed to reveal the glory of God, yet this glory cannot be seen in the structure of creation itself but only when creation is allowed to function as a revelation of that glory. Beyond or "behind" all creation is the creating and sustaining activity of God, but this activity is hidden so long as creation itself is specifiably known. In other words, "creation" has two complementary modes: creation as analyzed or specifiably known, i.e. "the heavens and the earth", and creation as applied or tacitly known, i.e. "the glory of God". The same considerations apply to the other examples cited.

It is worth noting that this complementarist approach provides an alternative to the model of revelation proposed by John McIntyre (A reveals B to C) in that revealer and revelation are two modes or poles of the same entity (A-applied and A-analyzed) rather than two separate entities (B and A).[34] Hence, <u>revealer and revelation are related modally rather than instrumentally</u>.

There is, however, one important difference between these examples of complementarity in theology and the type of complementarity we have studied in science. In science, the specifiable mode is always the (chronologically and ontologically) prior mode from which the tacit mode evolves (e.g. atoms→organism), hence <u>the directions of evolution and pointing are the same</u>. Things are built from the ground up so to speak. However, in theology things are built from the top down. Hence the tacitly-known mode is usually prior to the specifiably-known mode (e.g. Creator→creation) so that <u>the directions of "evolution" and pointing are opposed</u>. Note that the reversal of the direction of evolution and dependence occurs at the level of man - levels below man evolve upwards and those above man "evolve" downwards (the hierarchical relation). Hence this reversal simply reflects man's unique position in creation: he is the summit of natural evolution from the viewpoint of science and a "little lower than the angels" from the viewpoint of theology. It is an ontological reversal rather than a merely epistemological one based on an anthropocentric outlook. Once this curious reversal of dependence is understood the continuity and discontinuity between science and theology ceases to be a barrier, and the way is open to applying a concept like complementarity to theological issues (the problem of progressive adaptation).

The reversal of the direction of dependence manifests itself in several ways. For one thing the initiative in the knowing relations of science always lies with man - he is the questioning and knowing subject. But in theology the initiative lies entirely with God - man here is a questioned and known subject. Hence we speak of God's self-revelation rather than man's own discovery of God.[35] Another related point is that entities above or beyond man (e.g. creation as a whole or God in one of his modes) need not and cannot always be defined in terms of an environment or experimental arrangement since they have no "boundary conditions" in the absence of a human subject.[36] Hence the relational view of attributes derived from atomic physics is no longer applicable, and the possibilities of definition (presupposing a particular theological model)[37] may entail a subject-object boundary in the absence of a subject, even in Bohr's general sense of the term (i.e. experimental arrangement).[38] In other words, since we have no instruments for observing God (or for that matter the universe as a whole), we can only confront him directly and the modal character that we observe must be independent not only of the presence of a human subject (as in the sciences)[39] but of any kind of subject or environment. Then we must conclude that this modal existence is intrinsic to the entity in question. It is not simply a response to changes in the environment as in the sciences.[40]

When we come to experience these modal transformations (cf. the transfiguration of Jesus) we experience them as being spontaneous rather than merely responsive. Hence we conclude that our own modes of knowing (specifiable and tacit) are modelled on the modal structure of reality (structure and function) and we recognize the priority of God's self-revelation (the divine complementarity) to our knowing of it.

Footnotes: Chapter 6.

1. "I think you theologians should make much more use than you are doing of the principle of Complementarity." Bohr made this comment to John Baillie during a brief discussion after his 1949 Gifford Lectures; see J. Baillie, Our Sense of the Presence of God, p.217.

2. See ch.3.5 above.

3. "Parallelen zwischen der Theologie Karl Barths und der heutigen Physik", in Antwort: Karl Barth zum siebzigsten Geburtstag am 10. Mai 1956, Zollikon-Zurich, 1956, pp. 409-422; cf. "Vorbemerkungen zum Gespräch zwischen Theologie und Physik", Evangelische Theologie 1/2, 1947, pp. 64-92, and Der Mensch und die Physik, Wuppertal-Barmen, 1954.

4. Der Mensch und die Physik, pp.10,54.

5. ibid, pp.51-54,60.

6. See T.F.Torrance, Theology in Reconstruction, pp.48f.

7. See above, pp.24f.

8. loc.cit., p.53, and "Parallelen, etc.", p.421; cf. ch.4.4 above.

9. See above, pp.24,138ff.

10. See above, ch.2.3, esp. fn.48.

11. Christianity in an Age of Science, pp.15f,20, and Science and Christian Belief, p.91.

12. Science and Christian Belief, pp.96-101.

13. Christianity in an Age of Science, pp.22-24, and Science and Christian Belief, pp.94-97; cf. ch.5, fn.12 above.

14. Christianity in an Age of Science, pp.25-26, Science and Christian Belief, p.88, and "The Similarity of Science and Religion", in I.G.Barbour, ed., op.cit., p.72.

15. Christianity in an Age of Science, p.29. The verses are from Pope's Essay on Man, I.267.

16. "Complementary Descriptions", p.392, and "Complementarity II", pp.105,114.

17. "Complementary Descriptions", p.391, and "Complementarity II", pp.116-117; cf. P.Alexander's criticisms of Mackay in "Complementary Descriptions", Mind 65, 1956, pp.150-151. Unfortunately, Alexander's definition of complementarity as a relationship between different sets of

features of a single object is not much better. This rather pointless debate continued in the papers given by two men at the First Birmingham Conference on the Philosophy of Religion in April, 1969.

18. "Man as Observer-Predictor", p.23, and "Complementarity II", pp.117-118,121-122.

19. He really means sign and idea-signified; cf. pp.103f. above.

20. "Man as Observer-Predictor", pp.27-28, and "Complementarity II", pp.120-121.

21. Issues in Science and Religion, Englewood Cliffs, 1966, pp.392-394; cf. "The Methods of Science and Religion", in H.Shapley, Science Ponders Religion, New York, 1960, p.214.

22. See above, p.109.

23. Issues in Science and Religion, p.393.

24. Waves, Particles, and Paradoxes, Houston, 1967; see also "Complementarity and Theological Paradox", Zygon 1, 1967, pp.365-381.

25. Waves, Particles, and Paradoxes, pp.28-31, cf. "Complementarity and Theological Paradox", pp.370-372.

26. Waves, Particles, and Paradoxes, p.30.

27. ibid, p.86; but see above, pp.16f,172. I.G.Barbour adds a third reason: (c) the models of humanity and divinity are not on the same logical level whereas wave and particle are (Myths, Models and Paradigms, London, 1974, p.152; cf. p.77). It is true that humanity and divinity are not on the same ontological level, but neither are wave and particle in Bohr's view since the former accounts for stationary states and stable atoms. It is also true that wave and particle are on the same logical level, or rather levels, since they may be compared at the classical level (where they are incompatible) and also at the quantum-theoretical level (where they are complementary). But the same could be said of humanity and divinity, whether on the "classical" Old Testament level or on the New Testament level in view of the Incarnation.

28. ibid, pp.93-96; cf. I.G.Barbour, op.cit., p.85.

29. See above, pp.87,109f.

30. See above, pp.91f,95,102.

31. See above, pp.107ff.

32. cf. L.Hodgson who refers to the generation of the Son (to

be considered below), the creation of the world, and the incarnation as "three 'moments' in the revelation of the divine nature" ("The Incarnation", in A.E.J.Rawlinson, ed., Essays on the Trinity and the Incarnation, London, 1929, p.377.

33. The application of complementarity to the relation between heaven and earth has been suggested by H.Rohrbach, "L'Image du Monde d'après la Science et d'après la Bible", La Revue Reformée 19, 1968, pp.66-67.

34. See above, pp.22f, esp. fn.149. This alternative has the decided advantage of circumventing the antinomies of "mediated immediacy" raised by R.A.Oakes, "Mediation, Encounter, and God", I.J.P.R. 2, 1971, pp.152-154; cf. J.B. Stearns, "Mediated Immediacy: A Search for Some Models", I.J.P.R. 3, 1972, pp.195-211.

35. See above, p.18; cf. T.F.Torrance, Theological Science, London, 1969, pp.97ff,130ff,232.

36. See above, pp.19f.

37. The paradigm here would be Bohr's original argument for the uncertainty principle based on the de Broglie model rather than his later appeal to the experimental arrangement in response to the objections of Einstein, Podolsky, and Rosen. See above, pp.10f. See also pp.93f for the alternative approaches in the field of biology.

38. See above, p.20.

39. See above, pp.24f.

40. While the modal character itself may be intrinsic to the entity in question, the potential of one mode for the other is intrinsic only for the ontologically prior mode. For the dependent mode this potential can only be one of response to the "giving rise" of the prior mode. See above, p.62.

Chapter 7

The Doctrine of the Trinity

> "When we confess that God is One we deny that He is single; for the Son is the complement of the Father /Patrem consummat Filius7, and to the Father the Son's existence is due." Hilary, On the Trinity 7.31 (p.132).

7.1 Introduction:

The doctrine of the Trinity is the ideal starting point for our study of complementarity in theology since it epitomizes the struggle of the early church as it experienced new depths to the reality of God and attempted to develop an adequate formalism to express its findings. The situation was remarkably similar to that of the physicists' first exploration of the quantum domain: there was the same breakdown of classical formulas, the straining of ordinary language, the emergence of numerous "paradoxes", and countless "heretical" oversimplifications. In both cases an "orthodoxy" emerged which attempted to do justice to all aspects of the reality concerned even at the expense of "common sense" and ordinary logic. The respective "orthodoxies" have had their adherents and their critics in every generation, and it seems almost as though a permanent stalemate has been reached in the respective sciences. However, a new possibility emerges with the recognition of the parallel between the two cases. Once the various issues and the contrasting positions can be identified in a variety of different sciences (including theology) they can be generalized and treated as a class rather than simply as isolated instances.

Once the various themes and fallacies can be abstracted from their particular contexts there is an immense gain in perspective, and a kind of metascience emerges. One may never be able to decide between (say) monist, dualist and complementarist models in a final way, but one can use the lessons learned in one area of application to test one's conclusions in another area.

Hence there is considerable benefit to be derived from the establishment of a plausible parallel between a theological problem like the doctrine of the Trinity and the principle of complementarity. But establishing such a parallel is not a simple task at all! Besides the vast chasm between scientific and theological discourse, there is the problem of defining the doctrine of the Trinity in the first place. Then there is the difficulty of pinning down the logic of that doctrine (so as to compare it with the eleven points of complementarity) when, in fact, it operates as an organic whole and stoutly resists any such analysis. Finally there is the question of how to evaluate the results of the comparison.

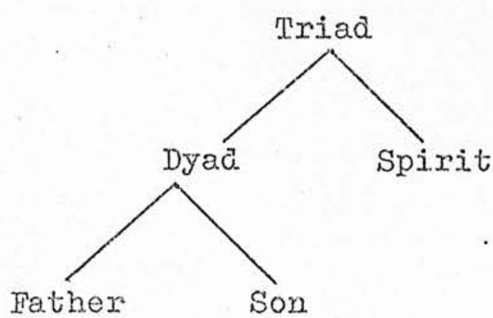
In this chapter I shall begin with a general discussion of various possible models of the Trinity with the intent of choosing those models which are most susceptible to a complementarist analysis. Then I shall treat the Father-Son relation in detail as a parallel to the eleven-point relation of complementarity and try to show how various heretical positions arise from the neglect of one point or another. Finally I shall evaluate these results on the basis of their comprehensiveness and logical fertility.

7.2 Models of the Trinity:

The first point to make clear is that we shall distinguish the transcendence-immanence (or essence-energies) relation which is directed towards creation (processio ad extra) from the intratrinitarian relations which are transverse to the former (processio ad intra). In other words, we shall assume with Irenaeus, Origen and later Fathers[1] that the generation of the Word and the procession of the Spirit are eternal acts in themselves and not merely preparatory or relative to the creation of the world.[2] In so doing we reject what seems to be the current trend in Western theology[3] and side with the more traditional view of the East.[4]

Secondly, we must decide whether to apply complementarity to the relations between the persons themselves (as suggested in chapter 6.5) or else to the relation between the essence (ousia) and the persons as a group (hypostaseis) i.e. between the "oneness" and the "threeness" of the "triunity". In support of the latter application one might cite numerous statements by the Fathers to the effect that the persons are three in one respect and one in another.[5] However, complementarity is not applicable to the relation of viewpoints or dimensions, and mere "triunity" can be understood in terms of a much simpler model like the ordered pair, $x = 3$, $y = 1$ (from the vertical direction it appears to be three and from the horizontal direction it appears to be one). Moreover, the relation of complementarity in this instance would require an extreme essentialism on one hand (the mode of pure oneness) and complete tritheism on the other (the mode of pure threeness). In fact, the pure essence of God (without distinction of persons) is never known in the economic trinity and is generally thought to be a misconception when applied to the immanent trinity,[6] and, conversely, the individual persons are never known in strict isolation without the coinherence of the others.[7] "Social" or "organic" models of the Trinity have recently become popular due to their ability to combine threeness with oneness,[8] but according to our analysis these models could only account for one mode of the complementarity relation (i.e the holistic mode of "oneness") as in the case of social relations among men and the supra-individualistic nature of mind.[9] Moreover, such models (cf. universals and particulars), though frequently used by the Fathers, were never taken literally as they tended to compromise the singleness of God's being in the direction of tritheism.[10] In fact, they seem to do justice neither to the distinctiveness of the persons nor to the unity of the essence. However, both of these conditions are satisfied *a fortiori* once we apply complementarity to the relationship between the persons themselves since both singleness of being and exclusiveness of modes are postulated from the start. Moreover, as we have seen the Father-Son and Spirator-Spirit relations embody the same giving rise and pointing back that one would expect of a complementarity relation.[11] Furthermore, the later Fathers frequently compared the Father-Son relation to the relation of thought and word[12] or of soul (mind) and body.[13] Since complementarity can be applied effectively to these latter relations[14] we may reasonably expect that the Father-Son relation will be a fruitful area of application as well.

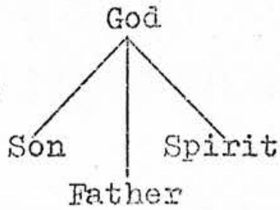
Finally, we must distinguish between hierarchical, linear, and triangular models of the Trinity and deal with the problem of the *filioque*. An hierarchical model would correspond to a procession of the Spirit from the Father *and the Son* equally. Here one would attribute to the generation of the Son a certain priority over the procession of the Spirit and so construct the Father-Son relation first in the model. Then from the Father-Son dyad *as a unit* one would derive the procession of the Spirit within a larger unit. A tree diagram of these relations would look something like this:

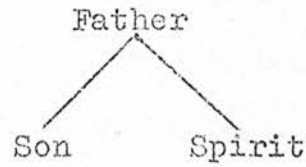


Reversing this procedure one could start with the essence of God (the triad) and then distinguish the persons by means of the traditional *relations of opposition*: procession would distinguish the Spirit from the Father and Son (the dyad) and generation would then distinguish the Son from the Father. Clearly this model corresponds to the traditional Western concept of the Trinity.[15] The characteristic features are the hypostatizing of the relations themselves and hence of the Father-Son dyad which operates like a unit[16] and the consequent subordination of the Holy Spirit.

A linear model of the Trinity would correspond to a procession of the Spirit from the Father <u>through the Son</u> and would treat the Son as a kind of middle term or intermediate case between the Father and the Spirit: e.g. the Father gives, the Spirit receives, and the Son both gives and receives like a channel between the other two.[17] Clearly this model is not susceptible to a complementarist analysis since either the coexhaustiveness or else the mutual exclusiveness of the two poles (Father and Spirit) would be impaired.[18]

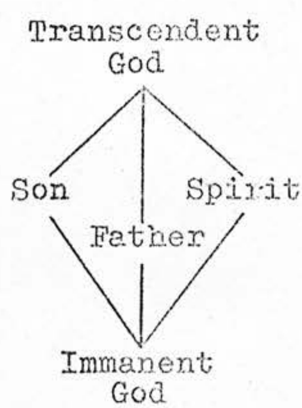
The triangular model corresponds to a procession of the Spirit <u>from the Father alone</u> and hence maintains complete symmetry and simultaneity[19] between the relations of generation and procession. Here there are two relations of complementarity: one between Father and Son and another between Father (Spirator) and Spirit. Complementarity between Son and Spirit is ruled out by their mutual reciprocity with the Father: the strict definition of the personal properties of the Father (fatherhood, unbegottenness) exclude the strict definition of the conjugate personal properties of the Son and Spirit (sonship, procession), and, conversely, the absence of the strict definition of the former requires the strict definition of <u>both</u> of the latter. Hence the triune God exists in three modes of subsistence but two of these (Son and Spirit) are synchronous. A diagram of these relations would look like this:





Here are two complementarity relations operating in unison and forming a kind of tetrahedronal structure which has the more familiar triangular pattern as its base.[20]

Both the hierarchical and triangular (or tetrahedronal) models can then be interpreted in terms of complementarity, hence, to first order, complementarity is <u>neutral with respect to the question of the filioque</u>. When it comes to relating the doctrine of the Trinity to the immanence and transcendence of God, however, there is a decided advantage to the triangular model in that it can easily be mirrored or inverted to produce the economic trinity whereas the hierarchical model cannot.[21]



However, it would perhaps be unwise to reach a decision on such a complex issue as the <u>filioque</u> on the basis of such a formal consideration. Therefore, we shall leave the question of the <u>filioque</u> entirely open, and, having shown how to relate the Spirit to the Father and Son with or without a filioque, we shall concentrate on the Father-Son relation alone to decide whether complementarity is a suitable category in the first place. Fortunately, the Father-Son relation is also the most discussed aspect of the Trinity in the patristic literature so there is no lack of data on which to base such a decision.

7.3 The Father-Son Relationship:

The purpose of this section is to compare the Father-Son relation point by point with the complementarity relation and evaluate the latter as an antidote to some common heresies. (1) Unity: For instance, the heresy of tritheism, as we have already noted, is automatically avoided by the postulate of unity - Father and Son (and Spirit) are one and the same God. But there is an apparent difference here, at least in emphasis, between the logic of the Trinity and the logic of complementarity. The Fathers generally argue for the unity of the divine persons on the basis of (a) their common properties (e.g. same nature, power and operation),[22] (b) their coinherence,[23] and (c) their relations of origin (i.e. the monarchy of the Father),[24] whereas in chapter 2 we accepted unity as a postulate, independent of the existence of common properties and then (using the idea of alternation) reasoned to the idea of "coinherence". Therefore, even apart from the meaning of these terms (which we shall consider below) there is the question of their logical relation to the postulate of unity itself.

(a) In fact, the fallacy of arguing for unity from the existence of common properties occurred to some of the Fathers as well, especially after the Council of Nicea and the canonizing of the term <u>homoousion</u>. Sometimes it was argued that Father and Son are both God in the same sense as Adam and Eve or Peter and Paul are both "man".[25] However, the limitations of this reasoning were also appreciated and the unity of Father and Son was recognized as a presupposition rather than a conclusion of the existence of common properties.[26] As John of Damascus puts it, men do not dwell within each other as Father and Son do, so their properties are only <u>similar</u> whereas those of Father and Son are actually <u>identical</u>.[27] (b) This brings us to the argument for unity from coinherence or interpenetration usually based on an interpretation of <u>John</u> 14.9ff. The point to recognize here is that the first Christians had a long tradition of experience with God (the Father) behind them so that when confronted with the person of Christ they had first to recognize the presence of divinity in the Son (coinherence) and then to infer the unity of Father and Son. In atomic physics the situation was quite the reverse: the particle-mode of matter was known first and the wave-mode was postulated for theoretical reasons even before wave-phenomena were actually observed.[28] Hence the unity (in some sense) of wave and particle was a foregone conclusion, and the idea of coinherence was largely an inference from this.[29] Hence this difference in emphasis between complementarity and the doctrine of the Trinity simply reflects the different historical developments of the two concepts and does not affect their intrinsic logic.[30] (c) The third argument for the unity of

Father and Son is based on the monarchy of the Father, that is, the derivation of the Son from the Father by generation. However, like the argument from common properties, this tended to lead to tritheism (or else subordinationism) since a father and his son are in general two distinct beings.[31] We may conclude, therefore, that the unity of persons (or modes of being) in the Trinity is logically a postulate in theology as it is in physics; it is closely related to the idea of coinherence yet the two are not strictly equivalent.

(2) Common Properties: The doctrine of the Trinity is unique in theology in that the extent of the properties common to the individual modes is maximal: all of the attributes of deity, the complete substance of deity,[32] and all of the *opera ad extra* are said to be shared by Father and Son. In short, all properties except for the relations of origin (*opera ad intra*) are held in common.[33] In the terminology of complementarity, all properties are common except for those that are conjugate to each other (e.g. fatherhood and sonship, see below). Regardless of the degree of symmetry or asymmetry between the modes the general form is still the same.

It is also said of the Trinity, however, that "those [common] properties which are in the Father are the source of those wherewith the Son is endowed".[34] This point is quite distinct from that of the monarchy of the Father because it pertains to the nature of the persons (which is common) rather than the persons themselves (which are distinct). As we shall see when we come to our discussion of Christology (chapter 10) it is analogous (within the format of complementarity at least) to the doctrine of the enhypostasia.[35] However, no analogous point has yet been recognized in the logic of complementarity. The equivalent would be to say that the common properties of two modes have their source in the prior mode (e.g. particle) and exist in the emergent mode only derivatively. In atomic physics, in fact, the properties of rest mass, charge and spin are regarded in the first instance as particle properties and are attributed to waves only because they are not subject to commutation rules. Hence, our understanding of complementarity may be enriched by the insights of theology as it is applied to various doctrines.

(3) Individual Completeness: As the condition of individual completeness distinguishes complementarity from modality or orthogonality[36] so it guards the doctrine of the Trinity against modalism and Sabellianism. In both cases the entity in question is fully present in each of its modes and does not merely offer one aspect or dimension to our view.[37] In contrast, Simon Magus taught that Father and Son were merely successive roles that God assumed,[38] and Sabellius held that they were merely two names for the same person.[39] Recently, the importance of this completeness or "radical self-manifestation" in the persons of the Trinity has been reemphasized by Karl Barth[40] and Karl Rahner.[41]

(4) Coexhaustiveness: The modes of Father and Son (and Spirit) completely exhaust not only our knowledge of God, but the being of God as He is in Himself. This means that there is no "essence" prior to or outside of the persons (i.e. no "quaternity")[42] and that the Father-Son relation is

exhausted by the persons of the Father and Son (i.e. there is no "grandfather" or "grandson").[43] Hence the Son completes or "complements" the Father as Hilary says.[44] However, the doctrine of the Trinity is even stronger at this point - there is one and only one Son, not a whole group of Sons as there are particles in an atom or atoms in an organism.[45] Is this purely coincidental? Definitely not! Since Father and Son are modes of God and uniqueness is one of God's attributes, both Father and Son must be unique just as both the mind and the body of man must be "human". Moreover, it may be possible to view this absolute uniqueness as the limit or extrapolation of the emergent uniqueness and individuality we noted earlier with regards to living organisms and men in particular.[46] This point will be taken up again when we discuss the subject of Christology in chapter 10.

(5) Equal Necessity: The point here is not merely that Father and Son are equal in honor and divinity (a point frequently made by the Fathers)[47] but that neither one can be eliminated or reduced to a limiting case of the other. Both are necessary for an understanding of God. The Fathers come closest to expressing this point by pointing to the very names, "Father" and "Son": there cannot be one without the other hence neither one can be excluded in favor of the other as if they were equivalent names for the same thing.[48]

(6) Alternation: In the logic of complementarity an entity evolves by alternation between its two modes. The question we must ask here is whether the generation of the Son (or procession of the Spirit) can be understood in

terms of such an "alternation". In the patristic literature the doctrine of the Trinity is frequently expressed in essentially dynamic terms.[49] However, the idea of a merely temporal alternation of an eternal being is explicitly ruled out as Sabellian.[50] Therefore, the dynamic of the Trinity is said not to be temporal but <u>supra-temporal</u>:[51] it is a matter of a causal sequence[52] or logical ordering[53] which is timeless and eternal.[54] The problem, of course, is that our language is permeated with temporal concepts: even when we discuss logical relations we inevitably use temporal terminology (e.g. "it follows that..."). Therefore, it must be recognized that such language is used <u>analogically</u>, that is, we recognize that there is a realm which transcends time and yet embodies relations that are formally analogous to our familiar temporal relations.[55] There is, of course, a problem here as to the very nature of time which goes far beyond the scope of this thesis. Suffice it to say that the postulate of supra-temporal relations is allied with the philosophical view that time is essentially a kind of ordering and that the notion of ordering or sequence is prior to that of time both logically[56] and psychologically.[57] So our conclusion is not that the generation of the Son is <u>like</u> the collapse of a wave into a particle, but that the generation of the Son stands in <u>the same relation</u> to the eternal consubstantial union as the wave-particle alternation does in relation to the temporal evolution of atomic objects. The analogy between the various features of the doctrine of the Trinity and the eleven points of complementarity is one of <u>proportionality</u> and not one of direct <u>proportion</u>.

Aside from the problem of the status of supra-temporal relations there is the question of the propriety of the particular relation suggested by the term "alternation". In the sense in which this term was used in our discussion of complementarity it would imply that the personal properties of the Father (fatherhood, unbegottenness) are "alternately" (in the supra-temporal sense) explicit (well-defined) and implicit (ill-defined) as the intra-trinitarian life "proceeds".[58] Conversely, the personal properties of the Son are "alternately" implicit and explicit. Moreover, there should be some real "development" or "evolution" of the Godhead as this alternation proceeds. Indeed, the generation of the Son would represent just such a development, and it would presumably be accompanied by a progressive definition of the characteristic properties of "sonship". But is it accompanied by a reciprocal diffusing of the characteristic properties of "fatherhood"? If not, then we must have either two Gods or else a contradiction of terms according to the logic of complementarity. Moreover, does the Son "regenerate" the Father so as to complete the cycle as suggested by the term "alternation"? Certainly the Fathers forbid us to think in terms of a reciprocal decanting and filling up as in the case of empty vessels as if the Father and Son were not individually full and perfect,[59] but this condition is adequately met by our insistence on the individual completeness of the modes which holds whenever the conditions necessary for the definition of their respective properties are satisfied. Moreover, the concept of _perichoresis_ popularized by the later Fathers embodies the notion of reciprocation or revolution or alternation as well as coinherence or interpenetration (<u>choreo</u> = 'to go' as well as 'to contain') although it is never explicitly used in this sense in regard to the doctrine of the Trinity.[60] So the alternation of generation and "regeneration" is a distinct possibility. However, it is also possible that the ordering of "eternity" is not an endless sequence as we imagine our time to be. We cannot place any <u>a priori</u> restrictions on this ordering at all, and it may be as simple (and as profound) as the sequence, one-two. In other words, there could conceivably be just two moments in the supra-temporal ordering of eternity, one corresponding to the Father and the other to the Son (and the Spirit?). In this connection it is worth noting that Brouwer regarded the intuition of "bare two-oneness" to be the foundation of all mathematics.[61] Rather than interpret the generation of the Son as a recurring alternation like those with which we are familiar in time, it might be possible to use the more familiar notion of the generation as an irreversible once-for-all "event" to define the character of the supra-temporal ordering itself. Obviously, we can do no more than raise these possibilities here, but one of the main reasons for using a concept like complementarity is simply to suggest new ideas like this one.

(7) <u>Coinherence</u>: Closely associated with the idea of alternation in the logic of complementarity is the "coinherence" of the two modes; i.e. each mode exists as a potentiality[62] within the other. Applied to the generation of the Son by the Father this would mean that the Son first

exists as a "potentiality" within the Father and then the Father exists as a potentiality within the Son he has generated. Hence the "interpenetration" and "interparticipation" of the two modes. Aside from the problem of using temporal language analogically, which we have already noted, this notion is very similar to the idea of coinherence used by the Fathers. For instance, the generation of the Son is said to be due to the nature of the Father rather than his will.[63] Hence the Son must be present even in the primordial nature of the Father, and since this nature is anterior (logically, not temporally) to the generation of the Son, the Son may be said to exist as a potentiality within the Father even prior to his own generation.[64] Conversely, the Father is in the Son as the sun is in its radiance or the fountain is in its stream,[65] i.e. by virtue of the generation (and the possibility of "regeneration"?). Hence, Father and Son are said to envelop and contain each other,[66] so that the two are interwreathed and mutually permeative - not like two physical objects (say the roots of two trees) but like a man and his portrait[67] or an object and its mirror image.[68] In short, when one mode is present the other inheres within it, and when one does something (<u>ad intra</u> as well as <u>ad extra</u>) the other participates in that action. As we have seen the same might be said of the wave and particle modes of an electron.[69]

The fact that the Father is present in the Son <u>as a potentiality</u> rather than an actuality (as say an actor in a disguise) guards the concept of coinherence against the error of Patripassianism.[70] The Father may be said to participate in the suffering and death of his Son, but he is not the actual subject of that suffering.

(8/9) Mutual Exclusiveness and Reciprocity: In contrast to the Sabellian identification of Father and Son[71] the Fathers saw that the two persons could not be equated since they are diametrically opposed like day and night.[72] The very names Father and Son indicate this for noone can be his own father or his own son. Nor can the two be reduced to a common denominator like matter and energy or (to some extent) space and time. In complementarist language, the two are mutually exclusive in thought, experience and reality. Accompanying this exclusiveness is a reciprocity or opposition between their personal properties.[73] As Basil says, these properties (unbegottenness and begottenness) cannot possibly coexist in the same subject.[74] Hence, in contrast to the common properties, they are incommunicable.[75] In the language of complementarity we would say that only one of a pair of conjugate properties can be explicitly defined in a given instance (e.g. begottenness in the Son); the other may be present by virtue of the coinherence, but only implicitly.

(10/11) Emergence and Pointing: Again the idea of emergence could be inferred simply from the use of the names Father and Son. While there is no actual subordination of the Son, it is recognized that the Son owes his being to the Father and hence the Father is "greater" than the Son (John 14.28).[76] Further, the Son acknowledges his source and points back to it like a faithful image or portrait.[77] As Irenaeus puts it, the Father is the invisible of the Son and the Son is the visible of the Father.[78] The point to stress here is that this "pointing" relation is not limited to historical revelation; it is "from the beginning of time"[79] and founded upon the eternal generation of the Son.[80]

7.4 Evaluation of the Comparison:

In favor of the use of complementarity as a model for the Trinity we could cite (a) the clear specification of alternate models with or without a filioque, (b) the comprehensive coverage of the logic of the Father-Son relation, (c) the built-in safeguards against tritheism, modalism and subordinationism, and (d) the fruitfulness of the model in providing new insights into an ancient topic (e.g. the logical relation of unity, common properties and coinherence or the possible nature of supra-temporal ordering suggested by the idea of alternation). Conversely, the logic of the Trinity has contributed something to our understanding of complementarity, namely the location of the source of all common properties in the ontologically prior mode. However, there is still considerable uncertainty as to the propriety of a concept like alternation and also as to the strict equivalence of the theological and complementarist notions of coinherence. Moreover, the application of complementarity is limited to those models of the Trinity that relate the three persons in dyadic pairs (Father-Son, Spirator-Spirit). If a linear model (Father-Son-Spirit) is preferred, then complementarity will not work at all. The fact that the assumption of dyadic pairs has allowed us to treat the Father-Son relation without any reference to the Holy Spirit underscores the artificiality of this approach. The most that can be said is that complementarity provides a possible model of the interpersonal relations of the Trinity and that this model has some very attractive features. This attractiveness would be greatly enhanced if the same basic format could be used in a variety of other theological topics for then not only would the many parallels stand out but the distinctive features and peculiarities would become more apparent, as well.

Footnotes: Chapter 7

1. Wolfson distinguishes the "twofold stage theory" of the Logos (endiathetos and prophorikos) of Justin, Tertullian, Novatian and Theophilus from the "single stage theory" of Irenaeus and Origen; H.A.Wolfson, The Philosophy of the Church Fathers: Vol.1. Faith, Trinity, Incarnation, Cambridge, Mass., 1956, pp.191-204.

2. e.g. Athanasius clearly distinguishes the generation of the Son from the opera ad extra; Or. con. Ar. 2.25.31.

3. e.g. J.R.Illingworth equates Father and Son with God-transcendent and God-immanent (The Doctrine of the Trinity Apologetically Considered, London, 1907, p.202), and C.C. Richardson equates Father and Son with God-absolute and God-related (The Doctrine of the Trinity, New York, 1958, pp.35-37,41-44,68-70,73-74). The dangerous implications of this "Logos Christology" have become even more apparent in R.Panikkar's The Unknown Christ of Hinduism, London, 1964, p.120, and The Trinity and World Religions, Madras, 1970, pp.57,69.

4. e.g. V.Lossky distinguishes the "personal processions" of the Son and Spirit within the essence of God from the "natural procession" of the energies of God; The Mystical Theology of the Eastern Church, pp.70,86.

5. Tertullian, Adv.Prax. 2; Origen, Dialektoi pros Heralkeiden 2.

6. Basil, Ep. 52.1, Con.Eunom. 1.19, Hom. 24.3.4; Anselm, De Proc.Spir.Sanct. 1; Calvin, Inst. 1.13.25; Barth, Church Dogmatics 1.1,ch.9.4, p.439; Rahner, The Trinity, London, 1970, p.112.

7. Basil, Ep. 38.4.

8. e.g. L.Hodgson, The Doctrine of the Trinity, London, 1943, pp.89-96. For a critical review see C.Welch The Trinity in Contemporary Theology, London, 1953.

9. See above, pp.108f.

10. See J.N.D.Kelly, Early Christian Doctrines, 4th edn, London, 1968, pp.265-268; G.L.Prestige, God in Patristic Thought, London, 1964, ch.13; and F.W.Green, "The Later Development of the Doctrine of the Trinity", in A.E.J. Rawlinson, ed., op.cit., pp.282ff.

11. See pp. 237-238 above.

12. e.g. Athanasius Or.con.Ar. 3.3.

13. Basil, Ep. 8.2; Augustine, De Trin.; Richard of St. Victor, De Trin. 3.10,11,4.10,5.14.

14. See chapter 3.3 above.

15. Augustine, De Trin. 5.5,6,8,11,15; Anselm, De Proc.Spir. Sanct. 1; Aquinas, Sum.Theol. 1a,29,4,30.1,32.3; Richard of St.Victor, De Trin. 5.14, Rahner, The Trinity, pp.68, 71-72.

16. Anselm, De Proc.Spir.Sanct. 10,14,15.

17. Richard of St.Victor, De Trin. 5.14.

18. See above, chs.2.4,2.8.

19. John of Damascus, De Fid.Orth. 1.8; cf. the "two hands of God": Irenaeus, Adv.Haer. 4.20.1,5.1.3.

20. cf. the medieval "emblem of the Trinity"; e.g. H.Child and D.Colles, Christian Symbols, Ancient and Modern, London, 1971, pp.49-50.

21. This diagram is purposely ambiguous in that it may be read either vertically (transcendent God is Father, Son and Spirit; immanent God is Father, Son and Spirit) or horizontally (the Son is transcendent and immanent, etc.). Thus it combines the doctrine of the Trinity with the doctrine of transcendence and immanence and clearly illustrates the relationship of transverseness between them. Note the difference between this diagram and the one shown on p.102 which represents the complementarity structure of man.

22. Hippolytus, Con.Noet. 8 (one power); Basil, Con.Eunom. 4.1.1 (identical operations); Didymus the Blind, De Trin. 2.6.4 (same honor and operation); Gregory of Nyssa, Non tres Dei (one operation); Gregory of Nazianzus, Orat. 31. 16 (one essence and power); Hilary, De Trin. 7.21 (same honor and works); John of Damascus, De Fid.Orth. 1.8 (same will, operation, power, authority, and movement).

23. Hilary, De Trin. 7.41,8.56; John of Damascus, De Fid. Orth. 1.8.

24. Tertullian, Adv.Prax. 2; Gregory of Nazianzus, Orat.40.41, 42.15; Hilary, De Trin. 3.4,9,57.

25. Gregory of Nazianzus, Orat. 37; John of Damascus, De Fid. Orth. 1.8.

26. Gregory of Nyssa, Non tres Dei; Gregory of Nazianzus, Orat. 31.11,15.

27. De Fid.Orth. 1.8. (taken over by John of Damascus from De Sacrosancta Trinitate of Pseudo-Cyril; see G.L.Prestige, op.cit., pp.263,281.

28. See above, ch.2, fns.61,62, ch.4, fn.84, ch.5, fns.40,62.

29. See above, p.60.

30. Occasionally the Fathers argue from unity to coinherence, as well; e.g. Athanasius, Or.con.Ar. 3.3.

31. See G.L.Prestige, op.cit., p.254.

32. Basil even spoke of the godhead or divine nature as a kind of invariant among the three persons; De Spir.Sanct. 18.45, Ep. 38.4.

33. "In Deo omnia sunt unum, ubi non obviat relationis oppositio"; Council of Florence (1441); cf. Gregory of Nazianzus, Orat. 20,31,34,41 (see J.Quasten, Patrology: Vol.3. The Golden Age of Patristic Literature, Utrecht, 1960, pp.249-250).

34. Hilary, De Trin. 3.4 (On the Trinity, p.62).

35. cf. Leontius of Jerusalem, Con.Nest. 2.13, where it is said that the three persons are enousios in a single ousia (G.L.Prestige, op.cit., p.274). In the framework of complementarity, however, we are concerned with concrete modes of a single being whether in the doctrine of the Trinity or in Christology. Therefore, we hope to avoid Prestige's charge of abstract formalism in this sense.

36. See ch.2.3 above.

37. Athanasius, Or.con.Ar. 3.1 (each of them separately full and perfect); Basil, Hom. 24.3.4 (shining forth entire, while the Father remains entire); Gregory of Nazianzus, Orat. 23.11 (each is God by itself); Hilary, De Syn. 69 (He is not a portion, He is a whole); John of Damascus, De Fid.Orth. 1.8 (each has a perfect subsistence); Augustine, De Trin. 8.1 (nor is any of the persons less than all three together); Anselm, De Proc.Spir.Sanct. 1 (each one alone is wholly and perfectly God), 16 (God is wholly Father, wholly Son, and wholly Spirit); Calvin, Inst. 1.12.19 (in each hypostasis the whole divine nature is understood).

38. Irenaeus, Adv.Haer. 1.23.1.

39. Athanasius, Or.con.Ar. 4.25.

40. Church Dogmatics 1.1, ch.9.4, p.439.

41. The Trinity, pp.35,55,88,112.

42. Basil, Con.Eunom. 1.19, Ep. 52.1, Hom. 24.3.4; Calvin, Inst. 1.13.25.

43. Athanasius, Ep.ad Serap. 1.15.

44. "Patrem consummat Filius", De Trin. 7.31.

45. "God, being without parts, is Father of the Son without partition or passion...and being uncompounded in nature, He is Father of One Only Son"; Athanasius, De Decr. 11 (Tr., J.Quasten, op.cit., p.69).

46. See above, pp.93f,108f,158f.

47. Gregory of Nazianzus, Orat. 40,41; Hilary, De Trin. 9.46, 51.

48. Clement of Alexandria, Strom. 5.1(1); Athanasius, Or.Con. Ar. 3.6; Hilary, De Trin. 2.3.

49. Athenagoras of Athens, Suppl.10.3 (the Holy Spirit flows forth from God and returns back again like a beam of the sun); Novatian, De Trin. 31 (filius ad patrem revolvitur); Victorinus, Adv.Ar. 1.43, De Gen.Verb.29f.

50. Hippolytus, Ref. 9.10,11; Athanasius, Or.con.Ar. 3.4; Basil, Ep. 236.6; Gregory of Nazianzus, Orat. 29.1.

51. Origen, De Princ. 4.4.28; Gregory of Nazianzus, Orat. 29.2.

52. Origen, De Princ. 1.2.10; Gregory of Nazianzus, Orat. 25. 15; John of Damascus, De Fid.Orth. 1.8.

53. Tertullian, Adv.Prax. 2; Calvin, Inst. 1.13.18.

54. Origen, De Princ. 1.2.4; Basil, Ep. 52.2.

55. "When we try to avoid the suggestion of temporality in illustrating timelessness we are frustrated; for 'when', and 'before', and 'originally', cannot be divested of temporal implication, however hard we try. The only thing to do is to take eternity as denoting a period commensurate with supra-temporal realities..."; Gregory of Nazianzus, Orat. 29.2 (Tr., H.Bettenson, ed., The Later Christian Fathers, London, 1970, p.117).

56. The "relational theory"; see e.g. G.J.Whitrow, The Natural Philosophy of Time, pp.36-39; M.Bunge, "Physical Time: The Objective and Relational Theory", Phil.Sci. 35, 1968, pp.355,388; and C.A.Hooker, "The Relational Doctrines of Space and Time", B.J.P.S. 22, 1971, pp.97ff.

57. See e.g. J.Piaget, Psychology and Epistemology, Penguin Books, 1972, pp.10-11,59-60.

58. See above, p.64.

59. Athanasius, Or.con.Ar. 3.1.

60. See G.L.Prestige, op.cit., pp.291-294. Note also that Augustine speaks of the Father and Son as existing 'reciprocally' or 'in alternation' (invicem sunt, De Trin. 6.7.9).

61. L.E.J.Brouwer, "Intuitionism and Formalism", *Bulletin of the American Mathematical Society* 20, 1913, p.85.

62. See above, p.62, fn.85.

63. Athanasius, *Or.con.Ar.* 1.16,3.6,62,63,66; John of Damascus, *De Fid.Orth.* 1.8; Ambrose, *De Fide* 4.9.103; Augustine, *De Trin.* 15.20.38.

64. Hence the Son is proper to or immanent in the substance of the Father; Athanasius, *Or.con.Ar.* 1.29; Cyril of Alexandria, *Thes.* 32.284E.

65. Tertullian, *Adv.Prax.* 8; Athanasius, *Or.con.Ar.* 3.3; contrast the image of two lamps in a room or of two suns whose radiances wholly interpenetrate each other in a different sense (Dionysius the Areopagite, *De Div.Nom.* 2.4. Gregory of Nazianzus, *Orat.* 31.14).

66. Hilary, *De Trin.* 3.1.

67. Cyril of Alexandria, *Thes.* 32.311A, *Com. in Johan.* 28Dff.

68. Hilary, *De Trin.* 9.69.

69. See ch.2.7 above.

70. Tertullian, *Adv.Prax.* 1,2,11,29; Hippolytus, *Con.Noet.* 3.

71. Tertullian, *Adv.Prax.* 2,5,7,10; Origen, *Com.in Johan.* 2.2; Hippolytus, Ref.9.5,10,11; Athanasius, *Or.con.Ar.* 4.2,25.

72. Tertullian, *Adv.Prax.* 10; Athanasius, *Or.con.Ar.* 3.4; Hilary, *De Trin.* 1.17.

73. "...les proprietés des deux personnes sont en relation d'opposition mutuelle et se répondent l'une à l'autre comme par une symétrie inversée." Richard of St.Victor, *De Trin.* 5.14.959D (*La Trinité*, Paris, 1959, p.339).

74. Basil, *Con.Eunom.* 11.28.

75. Gregory of Nyssa, *Con.Eunom.* 1.22; Richard of St.Victor, *De Trin.* 5.13; Calvin, *Inst.* 1.13.6.

76. Tertullian, *Adv.Prax.* 9; Athanasius, *Or.con.Ar.* 3.3, Hilary, *De Trin.* 1.54.

77. Clement of Alexandria, *Protrept.* 10.98.3; Origen, *Com.in Johan.* 13.25.152, *De Princ.* 1.2.6,4.4.1; Athanasius, *Ep. ad Serap.* 1.20-24; Basil, *Hom.*24.3.4, *De Spir.Sanct.* 18.45; Hilary, *De Trin.* 9.1.

78. *Adv.Haer.* 4.6.5.

79. *Adv.Haer.* 2.30.9,4.20.6.

80. Basil, *Hom.* 24.3.4.

Chapter 8

God and the World: Transcendence and Immanence

"In this wise does God, from within and from without, control and correspond to the universe; being infinite He is present in all things, in Him Who is infinite all are included." Hilary, On the Trinity 1.6 (p.41).

8.1 Introduction:

The relation between God and the world is one of the most complex subjects in all theology, and, in contrast to the doctrine of the Trinity, there is no general agreement as to its precise nature, or even its epistemological status. Is this relation to be viewed as an analogy of being,[1] or an analogy of operations?[2] Or are both of these notions essential?[3] Moreover, is it proper to treat this relation independently of or prior to Christology? Does Christology depend upon the doctrine of creation for its theological formulation,[4] or does creation itself presuppose Christology?[5] Or is the relation between the two a circular one?[6]

These issues must be considered in due course, but they are not crucial at the outset. The fact that there is an analogy[7] between creator and creature and the general structure of this analogy are the relevant points. In a later chapter we shall inquire whether the structure of Christology is similar to that of the analogy at hand,[8] but the question of dependence is really a matter of the ordo decreti and here we are concerned primarily with the relationship between orders (e.g. the ordo decreti and the ordo salutis). Our approach is admittedly structural and "synchronic" and is not suited for the analysis of the "diachronic" dimension itself.[9]

Our task, then, is immensely simplified: we have just two terms, God and the world, and we want to discuss the relation between them. Moreover, the plausibility of a complementarist relation gains immediate support from the long-standing tradition of analogies with the mind-body problem.[10] However, whereas in the case of the Trinity we could appeal to a large body of material for verification in view of the underlying unity of understanding controlled by creeds and confessions, here we must be more cautious. Terms like 'transcendence' and 'freedom' have vastly different meanings for different writers and correlations between them are often misleading. Therefore, it is advisable to work with a single author even though this will make it more difficult to achieve comprehensiveness. Fortunately, we have an extremely thorough treatment of the doctrine of providence in Barth's Dogmatics III.3, and we can use this material as the basis of our investigation.

It is significant, however, that Barth avoids using the mind-body analogy in his discussion of providence. Whereas the relation between mind and body is largely reversible (in complementarist terminology the two alternate and interpenetrate in spite of the ontological dependence of one on the other), that between God and the world is not. God is immanent in all occurrence, but all occurrence is not immanent in God.[11] God "concurs" with the creature, but the creature does not "concur" with God.[12] In traditional terms God is "transcendent" as well as immanent, not just in a relative way, as mind "transcends" body (emergence and pointing),[13] but absolutely in the sense that God has his own (necessary) existence quite separate from and unrelated to creation as well as a relative and contingent existence which in itself may function as a "mind" to the "body" of creation (totum inter omnia et totum extra).[14] In short, we have two relations to consider, not just one. There is the obvious relation between (the immanent) God and the world and also the more abstract relation between the two modes of God,[15] transcendent and immanent, or absolute and relative,[16] or essence (ousia) and energies (dunameis).[17] In order to avoid the implication that the God-world relation is reversible or purely symmetrical we shall treat the transcendence-immanence relation first, and since Barth has very little to say on this subject[18] we need to supplement his thinking with the work of another writer. The best treatment I have found is that of Vladimir Lossky in The Mystical Theology of the Eastern Church[19] which is based on the thought of St. Gregory Palamas. In view of the current Western tendency to equate the generation of the Son with God's movement towards creation (logos prophorikos), it is not surprising that we are forced to turn to the Eastern tradition to find an adequate treatment of the transcendence (essence) and immanence (energies) of God.[20]

To restate the matter: if there were only two terms (or modes) to consider, it would be impossible to avoid the reversibility or symmetry between God and the world which Barth warned against, whereas in a three-term model the restriction against reversibility is incorporated into the ontological structure of the God-world relation. However, we must rule out the idea of a demiurge or intermediary between God and the world so two of the terms (transcendence and immanence or essence and energies) must belong to God himself. This, in turn, requires a "natural procession" within the being of God which is distinct from and orthogonal to the "personal processions" of generation and spiration. Hence, while their theological traditions are worlds apart, Barth and Lossky supplement each other quite nicely in this regard.

In the next two sections we shall discuss the two relations among the three terms separately, and in the final section we shall look at the connection between them.

8.2 Lossky's Concept of the "Uncreated Energies":

Lossky's treatment of the "uncreated energies" is highly condensed, and the main points are found in a few concise statements like the following:

> God is thus at the same time totally inaccessible and really communicable to created beings; neither of the terms of this antinomy [can be] excluded or minimized in any way. (p.68).

> Wholly unknowable in His essence, God wholly reveals Himself in His energies, which yet in no way divide His nature into two parts - knowable and unknowable - but signify two different modes of the divine existence. (p.86).

In these two passages alone one can find most of the characteristic points of complementarity: the single divine being and undivided (common) nature, the individual completeness ("<u>totally</u> inaccessible", "<u>really</u> communicable"), coexhaustiveness ("<u>two</u>"-ness), and equal importance of the modes ("neither...excluded or minimized in any way"), their mutual exclusiveness ("antinomy") and reciprocity ("inaccessible... communicable"), emergence ("in the essence and outside of the essence"),[21] and pointing ("God wholly reveals himself in His energies"). In fact, Lossky's basic dialectic of knowable and (known as) unknowable or analyzable and unanalyzable is virtually identical to the complementarity of specifiable and tacit knowledge or of analysis and application.[22]

We are left then with the problems of alternation and coinherence. Note that Lossky speaks of the energies of God as a "natural procession", a "processio ad extra", an "eternal manifestation", and a "natural outpouring".[23] From these verbal images we may conclude that the relation between essence and energies is thoroughly dynamic, albeit supra-temporal. Hence, we are confronted with the same issues that emerged in our treatment of the doctrine of the Trinity. Can the interplay between essence and energies be understood as an ongoing sequence like that between wave and particle, or is the apparent "one-twoness" of the procession ad extra to be taken as definitive in our understanding of this supra-temporal ordering? In either case, the natural procession ad extra must be allotted a dimension of its very own; it must not be confused with the personal processions ad intra. Both are supra-temporal; both may even be described as "eternal", but they constitute two different orders of eternity: One is directed towards creation in a kind of tandem relation (transcendence-immanence-world) while the other is entirely transverse.[24]

However, there is an important difference here between Lossky's conception of essence and energies and the logic of complementarity. In complementarity the single entity (God) evolves by an alternation of modes. This means that the "events" of this supra-temporal ordering, i.e. the eternal decrees, must involve both essence and energies, both transcendence and immanence, whereas Lossky wishes to restrict the decrees to the energies so as to preserve the "absolute repose" of the essence.[25] In other words, for Lossky, essence is static and energies are dynamic, so the decrees must be confined to the energies, whereas in complementarity the two are dynamically related so that no such restriction is required. If we accept the complementarity model here, we can say that the supra-temporal ordering of the processio ad extra is correlated with the ordo decreti, provided, of course, that we assume the decrees to be eternal and not just a temporal "concurrence". Then the procession ad extra is not just "once-for-all" but a sequence of processions which continues as long as necessary to produce the total number of decrees, whatever that might be. The relation between this order of eternity and time, or between the ordo decreti and the ordo salutis, will be discussed in section 4 below.

Coinherence of essence and energies is nowhere explicitly stated by Lossky, but it is readily inferred from his use of such expressions as "the being and action of God", and his reference to the energies as the "rays of His divinity", or the "expansive energy proper to God", or even the "glory of God".[26] The essence inheres in the energies as being in action, or the sun in its rays, and vice versa. So it seems that a doctrine of coinherence could be developed for the natural procession along lines very similar to those of the personal processions themselves. Moreover, the image of "being and action" is comparable to that of potentiality and actuality which we used in our discussion of coinherence in atomic physics.[27] In both cases, one mode is contrasted to the other and yet present as a potentiality within the other. The difference is that in atomic physics either mode can be actual while the other is potential whereas the polarity of being and action (for Lossky) is not reversible in this sense. Of course, this "irreversibility" is simply a result of the apparent "one-twoness" or "once-for-allness" of the natural procession and can be corrected once the notion of "absolute repose" is reinterpreted. So one can argue for a correlation with complementarity without too much difficulty even though the evidence is extremely thin, to say the least.

8.3 Barth's Doctrine of Providence:

Barth's style is far more expansive than Lossky's so we must treat him topically in spite of the greater tedium this involves. Virtually all of the distinctive points of complementarity can be documented from his Dogmatics III.3, but the principal area of difficulty turns out to be the first point, the nature of the unity between God and the world.

(1) There is no doubt in Barth's mind that such unity or solidarity exists; it is for him a primary expression of God's love and grace.[28] Nor is there anything especially

problematic about the fact that God freely accepts this solidarity - it is not imposed on him from within or without - for while the world is distinct from God and so may be chosen or rejected by him, it is in no way independent and would cease to exist if it were ultimately rejected. Hence there is an ontological dependence upwards here just as within the created sphere itself there is an ontological dependence downwards.[29] The only difference is that we may attribute free volition to God, but not to atoms.

The problem arises with respect to the character of this union. For Barth it is purely a unity of action, not one of being; the activity of God and that of the creature are one single action.[30] From the perspective of complementarity, Barth's apparent denial of any unity of being raises a difficult question: does the emphasis on action, as opposed to being, imply that God's solidarity with creation is only dynamical and not ontological? If this were the case, then complementarity would not be an appropriate category for the relation of God and the world for it could not be said that (the energies of) God and the world are complementary modes of one and the same (temporal) being. However, there are several factors that prevent us from reaching this negative conclusion:

(a) In Dogmatics II.1 Barth stresses the full presence of God's being in his revelational (i.e. covenant) activity, in general, and in the Incarnation, in particular.[31] (b) In Dogmatics III.1 Barth maintains that the covenant is the internal form of creation and, conversely, that creation is the external form of the covenant.[32] One is compelled to conclude that God is <u>fully</u> present in his providential as well as in his revelational activity, and, therefore, that his solidarity with creation is ontological and not just dynamical or operational.[33] Otherwise, one would be forced to say that God's presence in Christ is only dynamical, as well. (c) On the other hand, Barth's distinction between act and being may be related to Athanasius's distinction between the eternal essence of God, from which the Son is generated, and the dynamic energies of God, by which the world is created.[34] If this is the case, then Barth's denial of a unity of being between God and the world means that the world is created <u>ex nihilo</u> by God's immanent energies and is not eternally generated from God's essence as the Son is. But the distinction between essence and energies is itself an ontological one[35] so the solidarity between God and the world must also be ontological; that is, it pertains to (temporal) being as well as to activity.[36]

It should be stressed that this solidarity of being is meaningful only <u>within</u> the context of creation and providence and that it only pertains to the immanent 'energies' of God, not to his transcendent 'essence'. God (i.e. the energies of God) and the world are one, but God (essence and energies) is also one by himself, so there are ultimately two realities, one temporal and one eternal, and the energies of God participate in them both.

(2) Barth cites three properties or qualities of being that are common to both creator and creature: glory, wisdom or reason, and power.[37] The creature does not possess these in itself, however, but only insofar as it

participates in the glory, wisdom and power of (the immanent) God.[38] As the (common) properties which are in the Father are the source of those with which the Son is endowed, so the (common) properties which are in the immanent Godhead are the source of those with which creation is endowed.[39]

(3) Barth clearly indicates the individual completeness of God and the world: the events of history are caused wholly by the creator and wholly by the creature, not just partly by one and partly by the other.[40] Hence, there are no gaps in God's providence, no limit to his sovereignty,[41] and yet everything is left for the nature, activity, freedom and responsibility of creation.[42] This means that creator and creature do not share freedom and responsibility as if it were divided up between them, but it also means that the two are not merely orthogonal dimensions of some higher-order complex.[43] God is not the fourth or fifth dimension of the world! Nor is he a four or five dimensional being who includes our space and time as a kind of subspace.[44]

(4/5) In the operation of providence, itself, there are two and only two terms. The existence of creation complements the immanence of God as partner, servant, instrument, theatre and mirror.[45] This means that there can be no third term between the immanent God and the world, on one hand, and also that both of these terms are equally necessary and equally important within the context of time and history. Hence, the sovereignty of God does not render the activity of the creature superfluous.[46] The world is not absorbed or assimilated into the Godhead as in pantheism,[47] for while it is completely dependent on the operation of God's grace it is also the conditio sine qua non of that same operation.[48]

(6) In general terms, the idea of an alternation or dialectic between creator and creature is embodied in the classical scheme praecurrit-concurrit-succurrit which Barth follows in ch.49.2. The basic point is that the activity of God is always prior to that of the creature,[49] but this priority may be taken in two different senses. First there is a priority of order which is eternal and terminates on creation as a whole, and then there is also a priority in time which is continual and terminates on each event individually.[50] In the following section we shall discuss the first of these priorities in relation to the problem of time and eternity, but here we are concerned with the God-world relation in time. Barth discusses this priority at some length in connection with the problem of causality. Here the divine accompanying implies that the created order of cause and effect can never become a closed system in itself since it is open to the divine activity at every point in its history.[51] At every point God gives it form, even in the slightest movement of a leaf in the wind.[52] Hence God plays the role of a middleman between cause and effect or between effort and result. Our efforts are naturally directed toward particular goals, but it is always God who arranges the results, not just fate or chance or natural law.[53] For the man who knows God as Father this is a great source of assurance and hope; it also entails the imperative that he keep his eye fixed on God rather than just the goal itself.

We may conclude, therefore, that time and history progress by a continual alternation or dialectic between God and the world.[54] From a theological viewpoint, in fact, it is precisely this alternation that produces history, that makes time flow. Time is the continual interplay between creator and creature. Hence there is an absolute order and directivity to events even though the existence of such order and direction may not be apparent from an examination of the creature itself, especially on the microscopic level. In other words, the irreversibility of modal processes, which is only statistical at the atomic level[55] and relatively reliable at the organismic and human levels, is absolute between God and the world as a whole. God does not repent or change his mind like a man, and the unidirectionality of time which we experience bears witness to the fact. In a sense this feature of time, this puzzle of both physics and philosophy, can be taken as a sign of God's covenant faithfulness to his creation and to man in particular (Genesis 6 and 9).

(7) The coinherence of God and the world is understood from the fact that the presence, activity and glory of the creator exist in, with and under those of the creature,[56] and the creature in turn participates and cooperates in the existence, action, glory and power of the creator.[57] The two are not just parallel to each other but positively interconnected and coordinated.[58] Of course, there is an asymmetry here as well due to the fact that God transcends creation with his "essence" at the same time that he interpenetrates it with his "energies". The coinherence is complete only from the perspective of God's immanence, and the inherence of creation as a potentiality within God must be understood in this context. The world does not inhere

in God's essence since it is a product of his will - a creation - not a product of his nature as the Son is of the Father.[59] The same must be said with regard to the inherence of God as a potentiality[60] within his creation! We may take this to refer to the immanent glory, wisdom and power of God, but not to his transcendent essence. Again, there is a parallel here between creation and covenant: creation is summed up in man, man in Israel, and Israel in Mary. How then can Mary be theotokos if creation itself is not also the bearer of God's presence?

(8/9) The mutual exclusiveness and reciprocity of God and the world are relatively straightforward. God is not a creature, and the creature is not God![61] Nor is there any common denominator between the two; they are absolutely antithetical and utterly unlike,[62] each belonging to a distinct order of its own[63] and having its own peculiar properties.[64] One is causa pure causans and causa divina or creatrix, while the other is causa causata et causans and causa non divina or creata.[65] One is self-existent while the other is totally dependent,[66] and so forth. In the terminology of complementarity, these are all conjugate properties and their definitions must be reciprocal, that is, the better defined one is, the less well-defined the other, so that they may coexist in the single being of (immanent) God-and-the-world without contradiction. As the divine and creaturely modes alternate between actuality and potentiality, their characteristic properties alternate between being explicit and implicit, and so the course of events develops.

The difficulty here concerns the question of correlation between the states of alternate modes. We have observed that the degree of correlation increases from the level of atoms (wave and particle) to the level of man (mind and body) along with the degree of individuality and irreversibility.[67] At the supreme level of providence it would seem that the correlation is absolute and complete like the others. God withdraws his spirit and the creature perishes; he returns with his spirit and the creature revives (Psalm 104.29f). However, the character of God's providential activity will naturally vary from one level of creation to another,[68] due to the gradual emergence of normative behavior at the higher levels. At lower levels which lack any real correlation, God's control may be rather mechanical as Hodgson has suggested:[69] at each point of time the laws of nature specify a certain range of possible occurrences and God selects among these.[70] At the human level, however, the element of propriety is quite strong to begin with, so God's providence will naturally take the form of guidance and grace. Of course, we must resist the tendency to reduce these distinctly human qualities to the procrustean bed of mechanical categories.

(10/11) Finally we must recognize that there is a definite asymmetry between creator and creature even within the limited context of time. Even in his immanence God is not just a companion but the Lord of creation.[71] His order or level of existence is the superior one; that of creation is subordinate.[72] At the same time the world is the mirror and likeness of his glory and a witness to his wisdom and reason.[73] Hence the "emergence" of divinity is accompanied by a "pointing" relation from creature to creator.

8.4 Time and Eternity:

At this stage the two halves of this thesis, the approaches of science and theology, have come into contact, and the basic outline of a complementarist worldview is nearing completion. From the side of science we have built up a hierarchy to the level of man, and from the side of theology we have worked our way downward from God to creation. At each stage we have been faced with the problem of the nature of time or of the supra-temporal ordering involved, and certain conditions have emerged which must be fulfilled if the complementarist view is to be made viable. It would not be putting the matter too strongly to state that complementarity stands or falls with the peculiar view of time and eternity which it entails. Hence, our findings on this matter should be summarized and restated under a heading of their own.

We have shown that reality is hierarchically structured, that is, it has many different levels or domains, and these are connected in various ways: some are transverse and folded into each other (e.g. Father-Son and transcendence-immanence), some are related in tandem (transcendence-immanence and immanent creator-creature), and some are nested within higher domains (e.g. atom-organism within body-mind). Each of these domains involves two distinct modes, and the domain in question evolves by an alternation between these modes. Hence there is a sequence of mode-events, and this sequence defines a distinct ordering. There are as many kinds of ordering as there are domains, but due to the various connections between these domains the orderings may be divided into three groups: First, there are the eternal orders of Father-Son and Spirator-Spirit, which may be nested (with filioque) or else synchronized (without filioque).[74] Secondly, there is the ordo decreti which is also eternal in the sense of being supra-temporal, but not eternal in the same sense as the ordo trinitatis. Finally, there is a large group of temporal orderings which are nested within each other in a hierarchy presided over by the God-world relation of providence. This latter group constitutes time and history as we know it. Its ordering must be related to the ordo decreti, but the two are not necessarily the same. For instance, the decree of creation may be a single supra-temporal act connected via providence to a long series of historical events.[75] Furthermore, the decree of election or salvation may precede that of creation, as the supralapsarians held, in spite of the fact that the historical fulfillment of these decrees generally occurs in the reverse order with respect to a given individual. Hence we cannot say that time and eternity (in this sense) are exactly parallel, but, on the other hand, they are not strictly orthogonal either since there is a positive relation between them. Both are irreversible and have the same directionality in spite of the fact that their orderings are not identical.

From this particular perspective the complementarity principle becomes quite plausible, indeed, almost to the point of appearing trivial. The intuitive content of the principle, i.e. the contrast of analysis and application, has been a common theme in the history of philosophy.

Moreover, many of the distinctive features, like unity, individual completeness, mutual exclusiveness, and emergence, could have been written down _a priori_ simply from a careful consideration of the conditions that must be fulfilled in any satisfactory treatment of issues like the relation of mind and body or of God and the world. Other features, like alternation, coinherence, and reciprocity,[76] could almost be guessed at in an attempt to work out a solution which is consistent as well as comprehensive. Finally, although some of these points seem to run counter to our common sense view of time and continuity, they appear quite natural within a broader framework which defines time in terms of alternation rather than the other way around.

Footnotes: Chapter 8

1. e.g. P.E.Przywara, Polarity, London, 1935.

2. K.Barth, Church Dogmatics III.3, Edinburgh, 1960, ch.49. 2, pp.102-103.

3. H.U.von Balthasar, The Theology of Karl Barth, New York, 1972, p.273.

4. N.F.S.Ferré, The Christian Understanding of God, pp.138, 158.

5. K.Barth, loc.cit., pp.106,113 et passim.

6. cf. W.A.Whitehouse, "Christ and Creation", in T.H.L. Parker, ed., Essays in Christology for Karl Barth, London, 1956, p.127.

7. Since this is the third distinct use of the term 'analogy' in this thesis, it will be helpful to keep the following distinctions in mind. There is (a) the analogical use of language or "correspondence principle" relating the classical and complementarist realms of discourse (see pp.16ff above), (b) the analogy between two or more fields in which complementarity is applied (see pp.87,110 and below), and (c) the analogy between the states of complementary modes when there is a significant degree of correlation between them (see pp.107f above).

8. So K.Barth, op.cit., pp.49,102,106,134.

9. See above, ch.3, fn.93.

10. In recent times the analogy has been drawn in various ways by W.N.Clarke (The Christian Doctrine of God, Edinburgh, 1909, pp.274-275), S.Alexander (Space, Time, and Deity, London, 1920, vol.2, p.394), C.Hartshorne (The Divine Relativity, New Haven, 1948, p.155), and N.F.S.Ferré (The Christian Understanding of God, pp.61, 141).

11. K.Barth, op.cit., p.110.

12. ibid, pp.111-112.

13. So S.Alexander, op.cit., vol.2, p.396, and Philosophical and Literary Pieces, London, 1939, p.331; cf. A.P.Stiernotte's criticisms in his God and Space-Time, New York, 1954, pp.245-248.

14. So E.L.Mascall, He Who Is, London, 1943, p.126; and L. Gilkey, Maker of Heaven and Earth, New York, 1959, pp. 86-88.

15. See above, pp.234,251.

16. C.Hartshorne, The Divine Relativity, p.32.

17. V.Lossky, The Mystical Theology of the Eastern Church, ch.4.

18. In Dogmatics II.1, ch.29, pp.341ff, Barth gives an excellent discussion of the relation between God-concealed (freedom) and God-revealed (love) which is in many ways similar to Lossky's discussion of God's essence (incommunicable) and energies (communicable). However, Barth's concern here is not really with transcendence and immanence, as he says (p.344), but with a certain paradox involved in our knowledge of God which he correlates with a polarity of love and freedom in the attributes of God. From the viewpoint of complementarity this same paradox is involved in all knowledge although it becomes more acute as one ascends to higher levels of being. Furthermore, while Barth and Lossky both speak of God as revealing or manifesting himself, Barth is concerned with revelation to man whereas Lossky has in mind a natural procession in God which is independent of creation (The Mystical Theology of the Eastern Church, pp.74-75).

19. Essai sur la Théologie Mystique de l'Église d'Orient, Paris, 1944 (E.T., London, 1957), ch.4; cf. The Vision of God, London, 1963, chs.7-9.

20. See above, pp.247ff, esp. fns.3-4; cf. E.L.Mascall's critique of Lossky in his Existence and Analogy, London, 1949, pp.148-154. G.Florovsky traces the distinction between essence and energies back to the writings of Athanasius ("The Concept of Creation in Saint Athanasius", Studia Patristica 6, 1962, pp.55ff). T.L.H.Parker finds a similar distinction between the essentia Dei and the gloria or virtutes Dei in the writings of Calvin (Calvin's Doctrine of the Knowledge of God, Edinburgh, 1969, pp. 83ff.

21. cf. the terms 'greater divinity' and 'lesser divinity' attributed to Gregory Palamas (V.Lossky, The Mystical Theology of the Eastern Church, p.81).

22. ibid, pp.33,38ff. Hence one could say that cataphatic and apophatic theology represent "complementary viewpoints" in Bohr's sense. Anticipating the results of the following sections, we might note that the tacitness of God's essence is a second-order tacitness. The energies, themselves, are known tacitly as they are hidden in creation as a whole and also in theophany. The essence, in turn, is hidden in the energies so it is doubly hidden and, therefore, doubly "unknowable" (specifiably).

23. ibid, pp.74,75,89,94.

24. See above, pp.247,251, fn.21.

25. op.cit., pp.95-96,98; cf. H.U.von Balthasar, Liturgie Cosmique: Maxime le Confesseur, Paris, 1047, pp.89ff.

26. op.cit., pp.74-75.

27. See above, p.62, fn.85.

28. Church Dogmatics, III.3, p.94.

29. See above, p.239.

30. op.cit., pp.93,94,105,132,133-134.

31. Church Dogmatics II.1, pp.257ff.

32. Church Dogmatics III.1 (Edinburgh, 1958), pp.231f.

33. See E.Jüngel, Gottes Sein ist im Werden, Tubingen, 1965, pp.115f. Note how Jüngel shifts the emphasis from God's relation to man in revelation to God's relation to the world as a whole in creation and providence.

34. See G.Florovsky, loc.cit., pp.46f.

35. ibid, pp.56f.

36. See T.F.Torrance, Space, Time and Incarnation, London, 1969, pp.61f.

37. Church Dogmatics, III.3, pp.97,122f.

38. ibid, pp.53,122f.

39. See above, p.254.

40. op.cit., p.134; cf. Aquinas, Sum.Con.Gen. 3.70 (Reply 3): "When the same effect is attributed to a natural cause and to the divine power, it is not as though the effect were produced partly by God and partly by the natural agent: but the whole effect is produced by both, though in different ways, as the same effect is attributed wholly to the instrument, and wholly also to the principal agent." (E.T., J.Rickaby, Of God and His Creatures, London, 1950, p.242).

41. ibid, pp.13,53,133.

42. ibid, p.149.

43. ibid, pp.135-136.

44. ibid, pp.48,110.

45. ibid, pp.45-51.

46. ibid, p.133.

47. ibid, p.149.

48. _ibid_, pp.47-48.

49. _ibid_, p.134.

50. _ibid_, pp.120,164-165.

51. _ibid_, p.122.

52. _ibid_, p.133.

53. _ibid_, pp.153-154, 166-167.

54. _ibid_, p.8.

55. See p.66 above, esp. fn.114.

56. _op.cit._, pp.19,43,132.

57. _ibid_, pp.8,47,53,123.

58. _ibid_, pp.39,133.

59. See above, p.260; cf. V.Lossky, _op.cit._, pp.74-75.

60. See above, p.62, fn.85.

61. _Church Dogmatics_, III.3, pp.9,19.

62. _ibid_, p.102.

63. _ibid_, pp.133,135,137.

64. _ibid_, pp.98,104.

65. _ibid_, pp.98-99,104.

66. _ibid_, p.103.

67. See above, pp.107ff.

68. The relation between creator and creature differs from that between different modes of the creature itself in that it may terminate at any level. The effects of providence apply directly to atoms as well as to man (contra Aquinas, _De Ver._ 5.89), whereas the effects of mental activity apply directly only to the body as a whole and apply to atoms only indirectly through the body. In this sense, the immanent Godhead is not just the highest mode in the hierarchy of complementarities; he is really present at all levels.

69. L.Hodgson, _Essays in Christian Philosophy_, London, 1930, p.57 = _Towards a Christian Philosophy_, London, 1942, p. 108.

70. cf. E.L.Mascall, _Christian Theology and Natural Science_, London, 1956, esp. ch.5.3; and W.G.Pollard, _Chance and Providence_.

71. _Church Dogmatics_, III.3, p.93.

72. _ibid_, pp.108,112,133.

73. _ibid_, pp.49,52,122; cf. Calvin, _Inst_. 1.5.1.

74. See pp.249-252 above.

75. cf. R.C.Neville, _God the Creator_, Chicago, 1968, p.104.

76. It is worth noting that the concepts of 'alternation', 'coinherence' (or 'interpenetration'), and 'reciprocity' are closely related in Greek thought. All three are included in the patristic concept of _perichoresis_ (G.W.H.Lampe, _A Patristic Greek Lexicon_, Oxford, 1961).

Chapter 9

Heaven and Earth

> For the angels are part of the universe, in the sense that they do not constitute a universe on their own, but are combined with the physical creation to form one total world. Aquinas, Summa Theologiae 1a.61.3 (Vol.9, p.211).

> What exists and takes place in our sphere exists and takes place in the presence and with the participation of this other sphere, this counterpart, heaven. K.Barth, Church Dogmatics III.3, ch.51.2 (p.424).

9.1 Time, History and Theophany:

The outline of a complementarist worldview has nearly reached completion with the doctrine of providence, but not quite. This may be seen from a consideration of cosmology: God created the heavens and the earth, hence the domain of man is not the whole of creation and the possibility of higher created levels must be considered. But we have also reached the point (in our imaginary descent from God) where cosmology folds out into history, and creation leads to covenant and its fulfilment in Christ. We cannot proceed from providence to Christology without considering the intervening history, the long period of preparation with its many revelations and redemptions (both with a small 'r'). There are always the twin dangers of placing too much emphasis on the subject of theophany and then absorbing the incarnation into it as a special case, and going to the opposite extreme and treating the incarnation as being so utterly unique that all continuity vanishes. We have a very simple model for this relation in the correspondence principle: theophany and incarnation are related by the logic of analogy involving both correspondence and incommensurability.[1] That is, the concepts used in describing the incarnation (e.g. Son, Lord, Saviór) are taken over from the Old Testament background and cannot be understood properly apart from that background, yet they are so transformed by their new application that they take on radically new dimensions of meaning. Their connection is analogical and they cannot be reduced upward to Christology or (any longer) downward to mere theophany. The best policy for us is to treat the topic of theophany separately (remoto Christo), if only briefly, and because we have begun with the side of creation and providence we should treat theophany next in order so as to maintain the relative continuity of historical ordering.

In fact, history, as distinct from mere time, is very much bound up with the occurrence of theophany. The activity of God in providence guarantees an irreversibility of cosmic evolution (there may be cycles but not repetition or recurrence in the strict sense) including the evolution of man. But evolution is not history. In evolution a past may be "preserved" in some kind of fossil record, but this past has no direct influence on the present. In fact, there is no past; there is only the present existence of a fossil record which is also subject to decomposition and evolution. Hence the present "swallows up" the past. Then there is no real present either! There is only a succession of moments with an absolute order, a "B-series" of before and after, but no "A-series" of past, present and future.[2] There is no transience to time because all moments stand on an equal footing and there is no evolving past, no history, only a succession of events without any cumulative effect.

The appearance of man alone does not greatly alter the situation. Men are born and die just as stars do. The fact that man has evolved on this planet does make the birth of our solar system unique and so distinguishes that prehistoric event from a mere moment of time, but only because we attach lasting significance to the emergence of man, itself. After all, there may well be intelligent life elsewhere in the universe and the mere fact of evolution does not guarantee the lasting significance of even the human experiment. Quite the reverse! From the standpoint of modern science, man's days are numbered, indeed! Beyond the obvious threat of self-annihilation there is an unending succession of ever greater catastrophes awaiting us: geomagnetic reversals, the death of the sun, to say nothing of the chance encounter with black holes or anti-matter, and ultimately the death of our universe, whether a slow "heat death" through unending expansion or a return to the state of the "primeval fireball". Therefore, the emergence of man is neither unique nor irreversible _per se_. And if man comes to naught there is no real significance to his evolution, or the events that led up to it, and hence no history. All that general providence ensures is that time goes on, so that the death of the universe is different from its birth. Providence guarantees order and direction but not lasting significance.

Nor does the fact that man keeps historical records and remembers the past tell us anything other than that man has a mind and a culture and these evolve with him. Historical records and memory states can be absorbed into the present just like fossil records. We know the difference between present and past not because we have historical records but because we have _a history_, not because we have memories but because we have _a past_. The past and history are real for us, as real as the present and nature, but why? Because the past can change in the same way nature can. It is not just "over and done"; it lives and evolves along with us and our memories and records. It has a reality and an evolution of its own.[3] For example, the Russian Revolution "occurred" in 1917, but it wasn't a revolution in 1917; it might have "turned out to be" just a rebellion. So the character of an _historical_ event changes with time. It has a history of its own.[4] But still we are building castles in the air; the Russian Revolution may fail yet! In that case it might still be called a revolution, but the word 'revolution' would then be dead as it is (more or less) in 'French Revolution', and the death of the word would only reflect the death of the reality behind it. It might then take on new significance in relation to some other movement of history, but if all such movements are futile in the long run there is ultimately no significance at all, and no history.

It seems to me[5] that the archimedean point for a theology of history is to be found in the "event" of Good Friday and _its_ subsequent history. In itself, the event was crucifixion, humiliation and defeat of the worst kind.

More than that it was pointless, needless cruelty and stupidity. Good Friday was not good on Friday; it became good on Easter Sunday. It became victory, glorification, and resurrection. More than that it became necessary, meaningful, providential. It is for this reason that Good Friday (together with Easter Sunday) stands at the "center" of history.[6] As long as we can say 'Good Friday' and mean it we have an absolute sense of history. As long as the word 'good' is alive there is a past that evolves and influences the present.

What, then, is the special quality of Good Friday that makes it an archimedean point in this way? Here, of course, the Christian knows more than he can possibly say. But the sheer intensity of the reversal from defeat to victory is most significant. The widest gap was bridged, not in billions of years, but in a matter of days! Never have men witnessed such a dramatic reversal, and there is good reason to believe that the effects can never be undone. No counter-revolution of evil can ever reverse this reversal because the height and depth of evil were already displayed in the crucifixion itself. In other words, it was God's act of Revelation and Redemption, par excellence, and it is irreversible in the ultimate sense.[7]

Then how are we to understand the background of Old Testament revelations and redemptions? Certainly these lack the intensity and irreversibility of the resurrection, but, on the other hand, we could not apprehend the intensity and irreversibility of the resurrection if they did not have a relative intensity and irreversibility of their own. Therefore, we may see the origin and basis of history (not just our notion of history!) in the progressive theophany of the Old Testament.

Curiously enough, the general religious category of theophany is anything but historical in this sense. A "manifestation" of the 'sacred' or the 'holy' is invariably an escape from history through participation in the unchanging or eternal. It is both reversible and repeatable. Hence there is time but not history in the proper sense. The annual dying of the cosmic God is necessary and proper from the start, so it does not evolve and is not an objective reality with a history of its own. It is only within the Hebrew tradition that the quality of irreversibility emerges and hierophany becomes <u>theo</u>phany in the historical sense.[8] Rather than <u>man's escape</u> from history, the Old Testament emphasizes <u>God's intervention</u> within history; the former is reversible and repeatable, the latter is definitely not.[9] Hence we are at the border line between providence and theophany, between nature (human in this case) and history.[10]

Nonetheless, the Old Testament, itself, has a background. Its affirmations about Yahweh are to be understood in comparison and contrast with those of the religions of neighboring traditions. The concepts, motifs and literary conventions are all taken from the common fund of ancient near-eastern lore, another example of correspondence and incommensurability. For this reason it would be worthwhile looking at the general category of hierophany and comparing it with the concept of complementarity. Since there is nothing <u>intrinsically</u> historical about complementarity we might expect to find its basic structure repeated in hierophany and historical theophany alike.

9.2 Theophany in the Phenomenology of Religion:

The distinction between "numinous" and "natural" moments of consciousness was first elevated to the status of dialectic by Rudolf Otto.[11] He realized that sacred objects were not essentially different from others in outward appearance so that the apprehension of the sacred dimension was a matter of intuition or "divination".[12] Moreover, the "eternal" is apprehended within the temporal, penetrating it so-to-speak, and there is something puzzling about the sacred object even on the empirical plane which calls attention to its higher modality.[13] Clearly, a case for complementarity could be made here, but what would be the ontological status of this particular complementarity? Is the sacred discovered by man in the object itself, or is it merely invented as an idea while the object is transformed into a religious artifact?[14] Otto is not entirely clear on this point, but his Kantian outlook makes one suspect that he would not accept the distinction between discovery and invention.[15] Hence, his "idea of the holy" may well be a manifestation of man's creativity (important as it is in its own right) rather than a manfiestation of an objective reality.

More recently attempts have been made to approach the realm of the transcendent via linguistic philosophy and the sociology of religion. The late I.T.Ramsey emphasized the empirical foundation of religious language in life-situations that are experienced to be "strange" or "odd", for example, miracles.[16] He spoke of "disclosure", "religious discernment", and even "revelation", but these terms are equally applicable (as he used them) to the use of nick-names or the cracking of jokes, so are left in the domain of man and have yet to discover anything beyond. Peter Berger, it seems to me, has made a real breakthrough by admitting the historical relativity of all religious experience and yet allowing for real discoveries within the human sphere which he calls "signals of transcendence",[17] "phenomena that are to be found within the domain of our 'natural' reality but that appear to point beyond that reality."[18] He cites man's propensity for order, his experience of hope and outrage, and his invention of play and humor as examples.[19] Whatever our opinion of these particular "signals", there is no doubt that Berger regards them as God's messengers and not just human contrivances.[20] Could it be that we have been entertaining angels all this time without realizing it?

But the most thorough study of the phenomenon of hierophany has been done by Mircea Eliade, and it is in his work that we find the greatest similarity, and also the greatest clash, with complementarity. Working within the no-man's-land of phenomenology Eliade maintains complete neutrality between subjectivist and objectivist interpretations of religious experience. He appreciates the imperialistic role of man in all sacralizing activity and at the same time recognizes the increasing freedom of God to <u>manifest himself</u> under a variety of forms, culminating in the incarnation.[21] The significant point is that Eliade finds the same basic features in all manifestations of the sacred, a structure which he calls the "dialectic" or "paradox" of the sacred: the sacred always manifests itself in an object or event which is not sacred in itself, hence it limits itself and ceases to be absolute; it is concealed at the same time that it is revealed.[22] There is a coexistence of contradictory essences, a paradoxical coming-together of sacred and profane, absolute and relative, being and non-being, with a consequent breakthrough of one into the other. The sacred is embodied within the profane and the profane participates in the dimension of the sacred.[23] Eliade makes all this sound very mysterious, yet the overall pattern is very similar to complementarity and so could be rationalized if a clear decision could be reached as to the ontological status of the dialectic. There is one serious obstacle, however. As the term "non-being" suggests, the level of the profane lacks reality and efficiency; in fact, it is only an illusion and is cancelled out by the sacred.[24] As Eliade affirms, the archaic worldview has a Platonic structure in which objects are reduced to the status of epiphenomena in relation to their archetypes.[25] From the complementarist viewpoint this is a clear violation of the conditions of individual completeness and equal importance, and it is precisely at these points that a Christian doctrine of theophany should differ from the archaic view. This is most clearly seen in the case of the incarnation where belief in the full reality of Christ's humanity is an important criterion of orthodoxy. But it is no less true in the case of Old Testament revelations and redemptions which are essentially historical, almost to the point of being prosaic.

Hence there is a clear discontinuity between the archaic and biblical notions of theophany. The archaic view lacks the mundaneness, the historicity and irreversibility of the latter. Nonetheless, it provided a suitable point of departure for the biblical witness, a kind of proto-complementarity, which suitably adapted and corrected would provide the model for the Hebrew understanding of revelation and redemption.

9.3 Theophany in Christian Theology:

In a sense the entire creation may be regarded as a manifestation of God ("the heavens declare the glory of God"), yet it is only a manifestation as presence and power, not as event or person.[26] Theophanies, on the other hand, generally take the form of a voice from heaven, thunder and lightning, or else a visible form like a pillar of fire. God also appears in human form, either in dreams or in the visible form of angels.[27] In most of these cases the perceptible form is temporary, even ephemeral; it is created de novo, as it were, for the immediate purpose at hand.[28] Hence it lacks the extensive permanence of providence, on one hand, and the intensive permanence of the incarnation on the other. Moreover, as the cited examples indicate, the manifestation may be at any level of creation from the purely physical to the purely mental.[29] Then there are also the angels. Angels seem to be a special class of beings which are created and subject to providence, but only appear in the special service of God. They are permanently available instruments of theophany,[30] and, in this sense, they prefigure the incarnation more accurately than other forms of theophany although their appearances lack the novelty (i.e. departure from general providence) and irreversibility of the other forms.[31] But the existence of angels introduces an entirely new sphere into our worldview, the sphere of heaven as the permanent abode (or mode of existence) of the angels. In fact, there could be many such heavens corresponding to various ranks of angels, but, for our purposes, one will do: "In the beginning God created the heaven(s) and the earth". Finally, once the existence of heaven is recognized, there arises the possibility of God's manifestation at that level and his coming to earth from that level. In short, we have two relations to consider, not just one: there is the relationship of theophany between God and his creature at all levels (heavenly and earthly), and there is the relationship between heaven and earth, the heavenly theophany and the earthly theophany, and their respective modes of time (aevum and tempus).[32] We shall deal with each of these relations in turn.

One of the most thorough discussions of theophany in Christian literature is given us by St. Augustine.[33] In De Civitate Dei he begins by drawing a parallel between theophany and speech: God's substance is to his perceptible manifestation as a thought is to the uttered sound in which it finds expression,[34] a parallel which was also used in the patristic period to describe the relation between Father and Son.[35] Hence the relation of theophany is not one of identity; God and his perceptible form are mutually exclusive - one is invisible and immaterial while the other is both material and visible - yet one is seen and heard (tacitly) in and with the other. There are unmistakable(?) signs in the manifestation which point to the hidden presence of the substance itself.[36]

In his De Trinitate Augustine develops this basic theme into a lengthy discussion of the theophanies of Old and New Testaments. At the baptism of Jesus and at Pentecost the Holy Spirit was manifest as a dove, as a mighty, rushing wind and as tongues of fire. These changing forms point to the hidden, unchanging presence of God's Spirit in the same way that the vulnerable flesh of Christ points to the presence and power of God's Word.[37] The only difference is that the Spirit was only manifest in flesh, not actually made flesh, i.e. the creaturely forms were not joined in him permanently.[38] Here Augustine introduces the most apt formula for true theophany, the creature serving the creator: "All these things, then, were wrought through the creature serving the Creator, and were presented in a suitable economy to human senses."[39] This service is of a specific nature, over and above general providence, for the creature is transformed or even created de novo for the purpose at hand.[40] An example would be the class of events known as miracles, events in which God's ubiquitous power suddenly breaks through and becomes apparent to all by means of dramatic signs like the thunder and lightning on Mt. Sinai or the conversion of water into wine at the wedding in Cana.[41] Another example is the phenomenon of prophecy in which God imposes himself on the prophet in such a way that he bears the very person of God (cf. theophoros) in the actions and words of his prophesy.[42] However, the most remarkable example of the creature serving the creator for Augustine is the appearance and activity of angels. Sometimes angels constitute a theophany in themselves; God is figuratively signified by them, and, in the case of the giving of the law, Christ himself was present in the angels so that Israel's rejection of Christ was prefigured in its failure to keep the law as well as its persecution of the prophets (Acts 7. 51-53).[43] But even when the angels are not visibly present, they are instrumental in the effecting of other appearances, signs and miracles.[44] In fact, there may be considerable difficulty in any given case deciding whether the angels constitute the theophany or merely accompany it behind the scenes.[45]

Finally, Augustine tells us something of the mode of God's apparition to the angels in heaven based on Mt.18.10 and 1 Cor.13.12.[46] Actually there are two distinct possibilities here, but Augustine does not make himself clear. Either (a) God's "face" (or else his "energies")[47] is directly intuited by the angels simply on the basis of creation and providence (God upholds heaven as well as earth), or else (b) God condescends to a finite manifestation which is in heaven. In the latter case, heaven would be the terminus ad quem of the theophany proper, and the mission of the angels to earth would be a matter of providence so that the overall process would be twofold and indirect.[48] But, in the case of direct intuition, the angels themselves would constitute the theophany and God would appear in them on earth rather than just to them in heaven.[49] On a lower, more familiar, level the same options are open in the case of prophecy: God might appear to the prophet in a dream and the prophet would then translate the dream into his own words,[50] or else God might speak directly through the prophet.[51] The former case is a truncated theophany; the latter is complete, and it is on the latter that the incarnation is modelled (Heb.1. 1).[52]

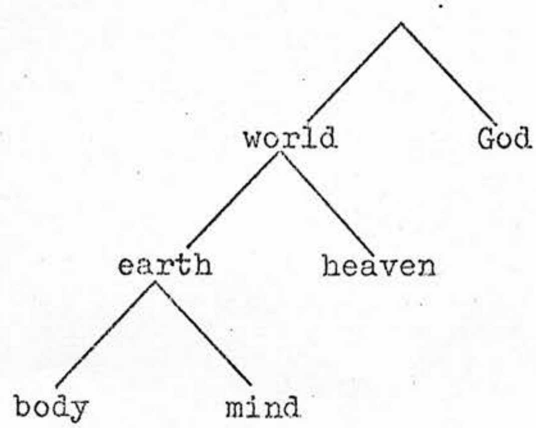
I have treated Augustine's ideas exegetically rather than topically, but I think the basic points of complementarity are evident enough. Of the eleven points, only unity, individual completeness, and equal importance are left in question. Augustine's concern to stress the disparity between God's substance and his creaturely manifestation sometimes leaves the impression that the creature itself is only an appearance, a kind of maya.[53] He also suggests (cf. option 'b' above) that the divine pole of the dialectic is eternal and unchanging so that the angels are needed as mediators between this blissful state and the world of time and change as if they were so many bodhisattvas.[54] In these instances, Augustine is perhaps closer to the archaic outlook than to the biblical view, although our analysis would indicate that correction at these points would leave the main body of his thought perfectly intact.

The gaps in Augustine's treatment are more than compensated for in Barth's discussion of God's "ambassadors" in Dogmatics III.3 (ch.51.3). To begin with, Barth stresses that within the context of theophany, God and the angel confront man together, in alternation, but as one and the same subject.[55] They share the same power, but God is the source of this power, and the angel is his <u>plenipotentiary</u>.[56] The angels have no existence or activity of their own; they have these only insofar as God is rich in relation to them, i.e. by participation in God's existence and activity.[57] Moreover, the angelic activity (and existence?) is <u>wholly</u> divine and <u>wholly</u> creaturely at the same time.[58] Hence, while angels are completely subordinate, they are <u>nonetheless</u> <u>real</u> in this subordination.[59] They share in God's speech and action on earth: when an angel is present, God is present; when an angel speaks and acts, God speaks and acts, and vice versa.[60] Yet thereis an infinite qualitative difference between the two: one is created, and the other is its creator; one is servant, and the other is Lord.[61] Finally, the angels are God's most perfect witnesses, consistently pointing away from themselves so that God is seen in them <u>sicut in speculo</u>.[62]

Here Barth gives us a classic statement of the epistemological correlate of complementarity, the dialectic of tacit and specifiable knowledge, or, as he puts it, "a state of increased and sharpened attention which has to be divided between the divine theophany as such on the one side and the cosmic or heavenly form in which it is both concealed and revealed on the other, between <u>God</u> in His mystery on the one side and God in His <u>mystery</u> on the other."[63] Hence, the witness of the angels provides the paradigm for all human witness. Prophets and apostles rarely achieve this perfection, and insofar as they do they actually take on the character of angels.[64] At this point, I think Barth has brilliantly succeeded in rescuing the doctrine of angels from the sphere of the occult and harnessed it to the central theme of biblical theology, the dynamic of witness and revelation.

9.4 Heaven and Earth:

Needless to say, we are not concerned here with two portions of space but with two modes of creation: heaven is the mode of the invisible, tacitly known, and earth is the mode of the (relatively) visible, specifiably known. Sometimes they are called "spiritual" and "material" or "physical", but when this terminology is used it should be remembered that the "material" earth includes man who is both mind and body and hence, in his own way, "spiritual" and "material". The terms are relative and are used in accordance with an analogy of proportionality within a hierarchical arrangement: God is to the world as heaven is to earth (man) as mind is to body, etc.[65]



This is the basic hierarchical structure of theology[66] according to which man is "a little lower than the angels". As such it is the straightforward extension of the hierarchy of the sciences (shown on page 102) within which man appears as the summit of evolution. But, for the moment, we are concerned only with the relationship of heaven to earth.

Again Augustine gives us a good start. The angels, he says, alternate between the heavenly mode, which is eternal, invisible and spiritual, and the earthly mode, which is temporal, visible and material.[67] In so doing they assume a physical body (and mind?) which is just as real as the spiritual one they enjoy in heaven, albeit more changeable.[68]

According to Aquinas[69] the angel is united to a physical body as the mover to the moved.[70] This union is similar to that of mind and body except that an angel is not limited to a single, fixed body as a human mind is.[71] The body thus represents or images the spiritual attributes and activities of the angel in heaven (e.g. an angel appearing to eat food is an image of spiritual nutrition!).[72] Hence, there is a kind of parallel or analogy between the sensible and intelligible (viz. spiritual) realms.[73] Moreover, there is a kind of interpenetration between the two: the angel itself may be said to be located at the place of the body to which his power is applied.[74] Hence the angelic realm and the physical realm constitute one single universe, not two separate worlds on their own.[75] While the angels are "in heaven" they are not "on earth", and vice versa,[76] so they must alternate between the two modes as they "evolve".

From the perspective of complementarity Augustine and Aquinas nicely supplement each other. Augustine stresses the equal reality of the physical and spiritual modes but neglects the unity of the two whereas Aquinas stresses the unity but leaves the impression that the physical manifestations of angels are merely symbolic and not as real somehow as the activities of the human beings they imitate.[77] The reason he gives is that if angels assumed real human bodies they would draw attention to their humanity rather than their spiritual actions and attributes (to say nothing of God!).[78] In other words, Aquinas wishes to preserve the feature of "pointing" by sacrificing the "completeness" of the manifestation and its consequent concealment of the spiritual. From our viewpoint this misjudgement reveals Aquinas's dependence on discursive reason and his neglect of the possibility of tacit knowledge.

Again we may turn to Barth for a more balanced treatment of the problem (ch.51.2). Heaven and earth, he says, are counterparts of each other within the one cosmos; creation consists not so much of heaven <u>and</u> earth as of heaven <u>in and with</u> earth.[79] Heaven complements earth as its partner and <u>alter ego</u>.[80] Hence, the two are equally real, each in its own peculiar way.[81] Heaven has a certain precedence (above, earlier, more) because God comes to us from heaven, but this precedence lies entirely within the radical equality of common creaturehood.[82] Hence earth's being "below" does not disqualify it in any way; its glory is not less but merely of a different kind.[83] Moreover, the intracosmic movement of God takes place from heaven to earth (and back to heaven) so that the relation is one of genuine intercourse or dialogue.[84] Nevertheless, the two modes are mutually exclusive; they may not be interchanged or confused. In fact, they stand over against each other as opposite poles.[85] Heaven is invisible, incomprehensible and inaccessible whereas earth is just the reverse,[86] yet in such a way that the execution of God's will on earth is accompanied by a revelation of heaven.[87] In other words, the dimension of heaven is not unknowable so much as it is tacitly knowable (i.e. not specifiably knowable) as the "other side" of events here on earth. All of this coincides exactly with the logic of complementarity, but the most remarkable feature of Barth's treatment here is his use of analogies with (a) the intra-trinitarian dynamic of generation and spiration,[88] (b) the relation of God and the world,[89] and (c) the relation of God and man in Christ.[90] Although Barth does not work this out in detail, he effectively summarizes the entire logic of complementarity in theology within the space of these few pages. And his support here is all the more auspicious for its lack of deliberation and self-consciousness.[91]

9.5 Aeviternity and Time:

Finally we should say a few words about the problem of the aevum or angelic time (tempus angelorum).[92] Most of the speculation on this topic has been controlled by the understanding that heaven and the angels stand in a closer relation to God than earth and man do. Since God is eternal and man is temporal, the reasoning goes, the mode of the angels must be intermediate. Hence Augustine concludes that, while not eternal in itself, heaven partakes in eternity by means of an unwavering contemplation of God which restrains its natural tendency to mutability.[93] Similarly, Aquinas maintains that angels and glorified saints share in God's eternity and thus rise above the mere succession of temporal moments through a vision of the divine Word.[94] Hence, "the aeon is neither time nor eternity but lies somewhere between the two".[95] Angels are eternal in the sense that they never cease to exist, but they are also able to move about, make decisions and think thoughts, all of which involve a kind of successiveness.[96] In short, their actions are accompanied by time, measured by the aeon, and participate in eternity. In another, rather more difficult passage Aquinas explains that the angels are above time as the measure of physical motion, but not above time as the measure of the succession from non-being to being or of the succession that occurs within their own heavenly activities.[97] In other words, they are created beings, not eternal, and they require their own proper time (aevum) as the measure of their peculiar evolution.

From the complementarist viewpoint, however, evolution does not take place within a given mode (e.g. heaven) but by alternation between that mode and its complement (in this case earth). Therefore, the successive moments of heavenly and earthly time are closely correlated and coordinated to form a higher order of time.[98] Moreover, this time of creation (heaven and earth) is in turn correlated and coordinated with the time of the immanent creator to form a single, all-inclusive time over against eternity of God (transcendent and immanent), alone.[99] Hence, the basic idea (put forward by Augustine et al.) that the respective times of man, the angels and God are hierarchically related can be appreciated as a profound insight. However, it would have to be rid of its Eleatic obsession with changelessness before it could become serviceable.[100]

Footnotes: Chapter 9

1. See above, ch.1.4 esp. fn.109; cf. E.Brunner, Revelation and Reason, Philadelphia, 1946, ch.7.

2. See R.M.Gale, The Language of Time.

3. cf. N.Berdyaev, The Meaning of History, London, 1936, pp.68-73; E.Lampert, The Apocalypse of History, London, 1948, pp.53f; K.Löwith, Meaning in History, Chicago, 1949, p.5; R.Bultmann, History and Eschatology, New York, 1957, pp.120,140f; J.McIntyre, The Christian Doctrine of History, Edinburgh, 1957, pp.91f; G.D.Kaufman, Relativism, Knowledge, and Faith, Chicago, 1960, pp.108ff; H.P. Rickman, ed., Meaning in History: W.Dilthey's Thoughts on History and Society, London, 1961, pp.106,162; J. Moltmann, Theology of Hope, London, 1963, pp.107ff,153f, and Hope and Planning, London, 1971, pp.83,175; W.Pannenberg, ed., Revelation as History, New York, 1968, p.142, and Basic Questions in Theology, Volume Two, London, 1971, p.62.

4. To my knowledge history and sociology are the only disciplines that have been, or even can be, applied to themselves. See J.T.Shotwell, The History of History, Volume 1, New York, 1939, esp. pp.3-9; and R.W.Friedrichs, A Sociology of Sociology, New York, 1970. The "history of history" has its theological counterpart in "tradition history" (Überlieferungsgeschichte), the attempt to trace the development of the theological interpretation of a given event back to its source. It should be stressed, however, that the changing interpretation is only a reflection of the changing significance. Significance is objectively real and accounts for the living reality of history whereas mere interpretation is purely subjective and would be "swallowed up" by the present moment if it were not anchored in objective significance.

5. The argument at this point might have been based on the cumulative view of the history of ideas implicit in Bohr's correspondence principle (see above, pp.13ff). The transformation of classical concepts (or, equivalently, Old Testament types) by their analogical application to modern physics (or the life of Jesus) would then provide the model for the transformation of historical events by subsequent history. In other words, there is a dialectical relation between past and present similar to that between analogue and counterpart (or type and antitype, or promise and fulfilment) although the former is much more general and the latter is only a special case. The conclusion we are about to draw is so intuitive, however, that this difficult line of reasoning would only tend to obscure it. Still it is worth noting this connection.

6. P.Tillich, The Interpretation of History, New York, 1936, pp.249f; O.Cullmann, Christ and Time, London, 1962, and Salvation in History, London, 1967.

7. "This identity in infinite contradiction is theologically understood as an event of identification, an act of the faithfulness of God. It is this that forms the ground of the promise of the still outstanding future of Jesus Christ. It is this that is the ground of the hope which carries faith through the trials of the god-forsaken world and of death." J.Moltmann, Theology of Hope, p.85, cf. pp.103,198f,225.

8. M.Eliade, The Myth of the Eternal Return, London, 1955, pp.104,107,148, and Images and Symbols, London, 1961, pp. 164,169.

9. "Directly ordered by the will of Yahweh, history appears as a series of theophanies, negative or positive, each of which has its intrinsic value. Certainly, all military defeats can be referred back to an archetype: Yahweh's wrath. But each of these defeats, though basically a repetition of the same archetype, nevertheless acquires a coefficient of irreversibility: Yahweh's personal intervention." M.Eliade, The Myth of the Eternal Return, p.107; cf. Cullmann's concept of an irreversible sequence of kairoi; Christ and Time, pp.39-44. B.Albrektson (History and the Gods, Lund, 1967) finds the concept of history in other Near Eastern religions but not the coefficient of irreversibility which creates history.

10. Hence the border line between the natural sciences and social sciences, between man as the product of nature (including "prehistory") and man as the product of history (Levi-Strauss calls these "complementary perspectives"; Structural Anthropology, London, 1968, p.18). Since a theological definition of man begins with Adam and the very first theophany (Genesis 2), it will be more concerned with history than with nature; cf. J. Moltmann, Theology of Hope, pp.142-143.

11. R.Otto, The Idea of the Holy, London, 1950, p.27.

12. ibid, pp.147,169.

13. ibid, pp.27,147,169.

14. See above, pp.103ff.

15. op.cit., pp.113f, 125.

16. I.T.Ramsey, Religious Language, pp.20,167; cf. E.C.Rust, Science and Faith, New York, 1967, pp.292,298.

17. P.Berger, The Social Reality of Religion, London, 1973, p.189.

18. P.Berger, A Rumour of Angels, London, 1970, p.70.

19. ibid, pp.70-96.

20. ibid, pp.111,119; cf. Schleiermacher's view that "anything can be called an angel that is a bearer of a divine message". The Christian Faith, Edinburgh, 1928, p.157.

21. M.Eliade, Patterns in Comparative Religion, London, 1958, p.11,29.

22. ibid, pp.26,29, and Myths, Dreams and Mysteries, London, 1960, p.125; cf. T.J.J.Altizer, Mircea Eliade and the Dialectic of the Sacred, Philadelphia, 1963.

23. The Myth of the Eternal Return, p.4, and Patterns in Comparative Religion, p.13.

24. Patterns in Comparative Religion, p.460, and Myths, Dreams and Mysteries, p.130.

25. The Myth of the Eternal Return, p.34.

26. K.Barth, Church Dogmatics III.3, pp.495-496; cf. M. Eliade, Myths, Dreams and Mysteries, p.153. From this viewpoint it seems plausible that the pagan gods are, in some cases, aspects of God's providence that have been isolated, hypostatized, and converted into idols; cf. H.L.Martensen, Christian Dogmatics, Edinburgh, 1866, p.129.

27. See Augustine's De Trin. 2.5-3.11 for a complete catalogue!

28. ibid, 2.6.11,2.7.12,3.10.19.

29. The absolute ban on the purely organismic level of animal forms noted by Eichrodt (Theology of the Old Testament, Volume Two, London, 1967, p.22) is broken only in the manifestation of the Holy Spirit as a dove at the baptism of Jesus.

30. In our view, however, the angels are not to be regarded as instruments of providence as Augustine (De Trin.3.4) and Aquinas (De Ver.5.8) held.

31. Augustine, De Trin. 3.11.26; Aquinas, Sum.Theol. 1a.5.2; and K.Barth, Dogmatics III.3, p.421.

32. Barth draws a nice parallel between these two relations in Dogmatics III.3, ch.51.2, pp.418ff, 494f.

33. De Civ.Dei 10.12-15 (E.T. Concerning the City of God, London, 1972, pp.390-393), De Trin. 2.5-3.11 (E.T. On the Trinity, Edinburgh, 1873, pp.52-106), and Confes. 12.9-15 (E.T. Confessions and Enchiridion, London, 1955, pp.275-282).

34. _De Civ.Dei_ 10.13.

35. See above, p.248, fn.12.

36. _De Civ.Dei_ 10.13,15.

37. _De Trin._ 2.5.10.

38. _ibid_, 2.6.11,7.12; cf. _Con.Maxim._ 1.19.

39. _ibid_, 2.15.25 (E.T., p.67). The idea is introduced in 2.6.11.

40. _ibid_, 2.6.11,3.10.19.

41. _ibid_, 3.5.11,6.11,10.19.

42. _ibid_, 3.10.19.

43. _ibid_, 3.11.26.

44. _ibid_, 3.10.19,11.22.

45. _ibid_, 3.11.

46. _De Civ.Dei_, 10.15,11.29,32, _De Trin._, 3.4.9, and _Confes._ 12.9.9,12.12.15,12.13.16,12.15.19-21.

47. See V.Lossky, _The Vision of God_.

48. Thus Augustine states that the angels hear the pure speech of God in heaven and then _translate_ this into successive audible sounds on earth; _De Civ.Dei_ 10.15.

49. Augustine's equation of God's "face" with his substance or divinity would support this view; _De Trin._ 2.16.27-17.28; cf. Aquinas, _De Ver._ 8.1,5.

50. _De Trin._ 2.18.34.

51. _ibid_, 3.10.19. Among modern scholars, J.Lindblom stresses the former alternative ("inspiration" as opposed to "possession"; _Prophesy in Ancient Israel_, Oxford, 1962, pp.11,158,310), and A.R.Johnson stresses the latter (an "extension of Yahweh's Personality" as opposed to a mere "representative" of Yahweh; _The One and the Many in the Israelite Conception of God_, Cardiff, 1961, pp.32f).

52. The ambiguity with regard to angels is deeply embedded in the scriptures, themselves, and may be related to the usual distinction between the intermediary angels (supposedly of Babylonian origin) and the _maleak Yahweh_ (see e.g. E.C.Rust, _Nature and Man in Biblical Thought_, London, 1953, pp.124-128). But, along with Barth, we may well ask, "What angel could be anything other, anything more or less, than an angel of God?" (_Church Dogmatics_ III.3, p.488).

53. See esp. De Trin. 2.15.26.

54. De Civ.Dei 10.15, De Trin. 2.5.10, Confes. 12.9.9,12.11.13,12.12.15,12.13.16,12.15.19-20.

55. "Now God, now the angel, and now God again; both in the same place and with the same function and as the same subject confronting man." Church Dogmatics III.3, p.491. "It is not that in this mediation He has beside Him a second acting and speaking subject, or a plurality of such, but that He always acts and speaks Himself in this mediation." ibid, p.478.

56. ibid, pp.457,459,484.

57. ibid, pp.480,493,498.

58. "In this mediation the doing of His will on earth is His work, the work of the living God, and therefore wholly divine, but as such it is addressed quite concretely to our creaturely sphere." ibid, p.478.

59. ibid, p.500.

60. ibid, pp.478,480,481,484,486,489,491,493,495,496.

61. ibid, p.484.

62. ibid, pp.461,481, 484,485,490,496.

63. ibid, p.491.

64. ibid, pp.497,499,513; cf. ch.11 below.

65. Aquinas, Sum.Theol. la.52.1-3; cf. fn.32 above.

66. The summit of the theological hierarchy shown here has been left undesignated. Possible headings would be 'providence' (see above, p.282) or 'time' and 'history' (p.280). Needless to say, each of these candidates has serious limitations; none of them adequately characterizes the all-encompassing nature of the God-world relation.

67. De Civ.Dei 10.15,11.34.

68. De Trin. 3.1.5.

69. Sum.Theol. la.50-64 (E.T. Vol.9, Angels, Cambridge, 1968), and la.110 (E.T. Vol.15, The World Order, Cambridge, 1970, pp.3-17).

70. Sum.Theol. la.51.2.

71. ibid, la.52.1,3,110.3.

72. ibid, la,51.2,3.

73. ibid, 1a.51.2.

74. ibid, 1a.61.3.

75. ibid, 1a.61.3.

76. ibid, 1a.52.2; cf. John of Damascus, De Fid.Orth. 2.3.

77. e.g. angels do not really sense, speak or eat through their assumed bodies; they merely imitate these activities. ibid, 1a.5.3.

78. ibid.

79. Church Dogmatics III.3, pp.421,424.

80. ibid, p.427.

81. ibid, p.443.

82. ibid, pp.419,422.

83. ibid, pp.431-432.

84. ibid, pp.428-432.

85. ibid, pp.422,458.

86. ibid, p.424.

87. ibid, p.477.

88. "this is how we describe the inner life of God, the opera Dei ad intra, in which the [intracosmic] movement [of God] to which we now refer has its basis and model." ibid, p.430.

89. "There is a correspondence, a similarity, of the relationship between heaven and earth to that between the Creator and the creature." ibid, p.419.

90. "They [heaven and earth] only reflect, but they do reflect, the true and proper and strict above and below of Creator and creature, of God and man. They attest the manner of this confrontation and conjunction; the relationship which is at issue in that encounter, history and fellowship and therefore in Jesus Christ; the relationship in view and for the sake of which the one whole cosmos is created." ibid, pp.421-422.

91. In fact, Barth explicitly rejects the entire notion of a worldview in his Credo, chapter 4 (New York, 1962, p.28), and Dogmatics in Outline, chapter 9 (New York, 1959, pp. 59f), though he seems to have the notion of a strictly autonomous worldview in mind. Significantly these categorical censures are absent from his more thorough treatment in Dogmatics III.3. In fact, of course, there is no

way to avoid *having* a worldview; the issue is how that view is to be controlled; cf. T.F.Torrance, "The Problem of Natural Theology in the Thought of Karl Barth", *Rel. Stud.* 6, 1970, pp.128ff.

92. cf. F.H.Brabant, *Time and Eternity in Christian Thought*, London, 1937.

93. *Confes*. 12.9.9,11.13,12.15,13.16,15.19.

94. *Sum.Theol*. 1a.10.3, cf. 10.1.

95. *ibid*, 1a.10.5 (E.T., *Vol.2*, p.149).

96. *ibid*, 1a.10.3-5.

97. *ibid*, 1a.61.2 (E.T., *Vol.9*, p.209).

98. "It is an unrelinquishable New Testament conviction that things inaccessible to empirical investigation really *happen* in that province which correspond with historically verifiable events... But this world must not be conceived as metaphysical and non-temporal; it must be included in the temporal process." O.Cullmann, *Salvation in History*, p.143; cf. K.Barth, *Church Dogmatics* III.3, p.500.

99. This is the relation of "nesting" mentioned on p.283 above.

100. cf. J.Moltmann, *op.cit.*, p.22. Note, however, that our formula of evolution by alternation gets around Moltmann's antithesis of revelation *upwards* (God of epiphany) and revelation *forewards* (God of promise). Along with Cullmann, moreover, we are placing more emphasis on the 'already' and not quite so much on the 'not yet'.

Chapter 10

The Humanity and Divinity of Christ

> "His body was for Him not a limitation, but an instrument [lit. 'He mastered it'], so that He was both in it and in all things, and outside all things, resting in the Father alone." Athanasius, On the Incarnation 17 (p.45).

10.1 Introduction - The Two Viewpoints:

Jesus is both the center of history[1] and the mediator between God and man,[2] but these two descriptions require two very different points of view. The first is diachronic and historical while the other is synchronic and ontological. The first is particularly suited to the study of Jesus' relation to us, to mankind past, present and future, while the other is best suited to the study of Jesus' relation to God.[3] The first is also suited to the study of Jesus' own history, his birth, growth, death and resurrection, and their significance, while the other is best suited to the study of the continual dynamic between God and man in Christ which provided the driving force for that history. Hence the former concerns the event of the unitio personalis while the latter concerns the state of the unio personalis.[4] Here we are primarily concerned with the latter, the ongoing dialectic between God and man within the concrete history of Jesus Christ, i.e. with the incarnation as a state rather than the Incarnation as an event. In the same manner we were concerned in chapter 8 with creation as the ongoing relation between God and the world rather than with cosmogony (or eschatology) as such.

Then where do we stand in relation to Pannenberg's Christology? Certainly Pannenberg would agree with our distinction between the historical and the (purely) ontological,[5] but he would reverse the relationship between the two. In his view, ontology, or the essence of things, is only manifest eschatologically and therefore is determined retroactively by history itself.[6] History generates ontology rather than the other way around. Hence the importance of Jesus' resurrection: by recognizing the qualitative presence of the eschaton in the resurrection of Jesus we come to know Jesus as God as well as man.[7] More than that, the fact that Jesus was both God and man in his lifetime is decided retroactively by the resurrection because it truly anticipates the end of all things.[8] If this is so then ontology has indeed been reduced to history and the traditional two-nature approach is both unnecessary and misleading.[9] What are we to make of this?

I accept Pannenberg's general view of history. His emphasis on the holistic nature of history and the 'retroactive force' (rückwirkende Kraft)[10] of significant events coincides almost exactly with the cumulative view of history and theophany set forth in the previous chapter. The only difference is that Pannenberg holds that historical events are inherently ambiguous and that they only acquire significance through the subsequent development of history[11] whereas, in our view, all events have objective significance from the start although that significance may change with the course of subsequent history. Pannenberg places so much importance on the future that he makes history (as it is) a mere appearance to be dissolved and displaced by the eschaton. Hence, rather than eliminating docetism he merely transfers it from a vertical emphasis on transcendence[12] to a horizontal emphasis on eschatology.[13]

However, that aside, I do not think Pannenberg's (or any) view of history explains the relation between the human and divine in Christ even if it does show how this relation was established. Either God was in Christ (the historical Jesus, that is) or he wasn't, regardless of the resurrection. What the resurrection tells us is not that "God was in Christ" but that he was "reconciling the world to himself" (2 Cor.5.19).[14] On the basis of the resurrection we know that God's commitment to us in Christ (in contrast to the O.T. theophanies) is final and irreversible; we know that our humanity has been joined to him <u>forever</u> and that not even death can separate us from the love of God. On the basis of the resurrection we know that Jesus' birth was <u>the</u> Incarnation and that his life and death were the final Atonement. But the ongoing dialectic of God and man within this framework is a distinct (though not separate) issue. It leaves open the question of what God was doing in the history of Jesus, but it cannot be reduced to or eliminated by any treatment of the historical question, however adequate. Therefore, even if we were to accept Pannenberg's view of history without qualification we would still be left with the question, "What is the ontological connection between the Logos and the human existence of Jesus of Nazareth?".[15] In particular, we must ask whether complementarity provides a suitable model for this connection.

10.2 Christology in Perspective:

In the next section we shall examine the complementarity model point by point, but first we must locate the problem of the "two natures" in relation to the other theological problems we have studied.

(1) Christology and the Doctrine of the Trinity: Recently both Barth and Rahner have stressed the fact that it was the Son or Word of God that became incarnate, not just God-as-such.[16] This point is clearly consistent with the complementarity scheme we have been using in which an entity only exists and operates in and through its particular modes of being so that the actual modality must be specified in any given case.[17] So when we speak of God in Christ we understand this to mean God in his actual mode as Son or Word and to include the Father and Spirit only by virtue of the mutual perichoresis.

(2) Christology, Transcendence and Immanence: In the same way that we must specify God as the Son we must also specify the Son as either transcendent or immanent, or, in Lossky's terminology, as either essence or energies, in Christ.[18] Inasmuch as the incarnation is an historical event/state it pertains to the immanent Logos as the actual mode and to the transcendent Logos only by virtue of their perichoresis. Thus, Lossky argues that the incarnation does not alter the essence of God because it is a (historical) manifestation of love and so pertains to the energies of God.[19] Aside from the difficulty raised by Lossky's view of love (= amor dei ad extra?), we may take his essence-energies scheme to be normative here as we already have in chapter 8.

(3) Christology and Providence: What is the relationship between the God-world relation of providence and the God-man relation in Christ, and what is the difference between the two? Perhaps the best answer to these questions has been given by Athanasius: the two relations the immanent Logos has with creation, providence and incarnation are radically different but they do not in any way exclude each other. The Word has alway filled creation as a whole, ordering and ruling it as its Lord, and he did not abandon this role when he became incarnate.[20] However, he entered the world in an entirely new way[21] in that he became uniquely related to a single part of creation (the humanity of Jesus) and he assumed the likeness of men rather than remaining just an unseen power.[22] In other words, the manifestation of God in Christ differs from that in creation-as-a-whole both in its intensity and in its personality, though not in its permanence.[23]

(4) Christology and Theophany: But the many theophanies of Old and New Testaments are also more intense and more personal than God's relation to the world in providence. How, then, does his activity in Christ differ from mere inspiration or appearance? Is the difference simply one of degree as Paul of Samosata held?[24] Is Christ to be regarded simply as the "supreme theophany"?[25] Again Athanasius seems to have the best answer. He frequently does refer to Christ's humanity as an instrument (organon) for the revelation of divine majesty.[26] However, he also points out that, if this had been the sole purpose of the Incarnation, other and better ways could have been devised to accomplish it.[27]

The Word could even have defeated death in other ways, but the benefits of his victory would not have applied to our humanity if he had not assumed a human body and experienced death himself.[28] Thus, whereas in the O.T. the Word came to individual men to hallow them and display himself in them, in the Incarnation he became man with a body of his very own so that all the properties and especially the weaknesses of the flesh also became his.[29] So the Incarnation involves an irreversibility and a permanence, a humiliation and a scandal that is absent from the O.T. theophanies.[30] Moreover, it entails God's final commitment to and redemption of man's history although this is only evident and only decided from the perspective of the resurrection.[31]

To summarize: from the synchronic viewpoint, emphasizing revelation and cosmology, there is a strong parallel between God's O.T. manifestations and his activity in Christ. Since complementarity is basically a synchronic model it may well be applicable to both. But from the diachronic viewpoint, emphasizing redemptive history, the two are very different, and this fact justifies our treating the two as separate problems.

(5) Christology, Heaven and Earth: "Who for us men and because of our salvation came down from heaven...and became human"; so reads the Niceno-Constantinopolitan Creed.[32] "He...rose on the third day...and ascended to heaven, and sits on the right hand of the Father, and will come again..." What is the meaning of all this coming and going with respect to heaven? There are two possible interpretations depending on whether the "heaven" involved is taken to mean the created

heaven or the uncreated abode of God. In the first case Christ's preexistence in "heaven" would have the character of a theophany in its own right and the incarnation would involve the transferal of this theophany from heaven to earth.[33] Such a "descent from heaven" would not be without parallels in the history of religions,[34] but it would find very little support among Christian divines, themselves. The Creed itself suggests that the "heaven" from which Christ "descended" is simply the "right hand" (i.e. the presence) of the Father, and there is a strong theological tradition from Hilary through Calvin which equates Christ's preexistence "in heaven" with his eternal Sonship or deity and therefore insists that he did not "leave heaven" (i.e. abandon his deity) when he "descended to earth".[35] Hence the '_extra Calvinisticum_'. However, this view makes it difficult to appreciate the full significance of the ascension and session. How can we account for the importance of these events in N.T. theology if we assume Christ to have been at the right hand of the Father all along? It may be that the only way to do justice to both the inalienable deity of Christ and the historicity of the descent and ascent is to think in terms of a heavenly court such as we find in the vision of John in the book of Revelation. This would not eliminate the '_extra Calvinisticum_'; it would only distinguish it from the issue of Christ's preexistence in heaven. Christ abandoned his place in heaven when he became man, but he did not abandon his deity.

(6) Christology, Body and Soul: It goes without saying (since the First Council of Constantinople condemned

Apollinarius in 381) that Christ assumed both the body and the soul of man; this point really comes under section 3(3) below. The issue to be considered here is the extent to which a parallel can be drawn between the unity of body and soul in man and the hypostatic union in Christ. This is really a preliminary skirmish in testing the relevance of complementarity to Christology: since the mind(soul)-body problem is itself a candidate for complementarity[36] and, moreover, since the body-soul relation has been used as a parallel in several of the other doctrines we have studied,[37] a parallel must also exist in Christology (in the synchronic sense) if overall consistency is to be maintained. In fact, such a parallel has considerable support from the Fathers,[38] including both Antiochenes[39] and Alexandrians[40] (though with differing emphases!). In recent times the analogy has been criticized by Barth[41] and received a thoroughly cautious assessment from H.A.Wolfson who lists three basic objections:[42] (1) Whereas the Logos completely dominates his humanity, the soul does not always dominate the body and there is sometimes severe conflict between the two; and (2/3) whereas the union of body and soul constitutes a new nature (i.e. human nature) which is present in the entire species of man, the hypostatic union is entirely unique and there is no Christic species. To answer these objections we must appeal to three of the principles developed in earlier chapters all of which come under the general heading of progressive adaptation.[43] First we recognize that there is a complete reversal in the direction of ontological dependence at the level of man in the overall hierarchy of complementarity; whereas lower levels evolve upwards and depend downwards, higher levels (including Christology) "evolve" downwards and depend upwards.[44] Secondly, there is the progressive emergence of correlation between alternate modes of an entity as one ascends to higher levels.[45] We have already seen that this correlation becomes complete at the level of providence,[46] and since Christology involves the same terms and the same levels (synchronically speaking) as providence the same perfection may be expected to apply to the relation between the humanity and divinity of Christ.[47] Together these two points answer Wolfson's first objection. Finally, there is the progressive emergence of individuality and uniqueness which we first noted in the nature of man himself[48] and later found carried to its logical conclusion in the absolute uniqueness of the Son of God in the doctrine of the Trinity.[49] The same uniqueness was present in the doctrine of providence (one God - one world)[50] and is here again present in the doctrine of the person of Christ. Whether one calls the union of God and man in Christ a "new nature" or not simply depends on whether one takes "nature" in the concrete sense of <u>prote ousia</u> (= <u>hypostasis</u>) or in the abstract sense of <u>deutera ousia</u> (= <u>eidos</u>).[51] In any case the analogy between the hypostatic union and the body-soul union holds provided that it is bracketed by the overall contours of the complementarity hierarchy.

10.3 Christology and Complementarity:

The rather tangled discussions of the previous two sections were designed to establish the framework for a point-by-point comparison of the two-natures doctrine with the logic of complementarity. As in previous chapters our procedure will be to use the format of complementarity developed in chapter 2 as an outline for the analysis of Christology.

(1) Unity: For all the debate over the use of words there is no doubt in anyone's mind that Christ is numerically one; the human and divine natures are united without division (adiairetos) and without separation (achoristos) as the Council of Chalcedon insisted. But the question remains; "One what?" and "what kind of union?" Even the Nestorians agree that the two natures constitute one prosopon[52] by virtue of their conjunction (synapheia).[53] On the other hand, the Monophysites insist on a much stronger union (henosis)[54] resulting in an entirely new, single nature (mia physis tou theou logou sesarkomene)[55] understood in the concrete sense of the term. The "orthodox" solution has been something of a compromise: Christ is held to be one prosopon and one hypostasis in two natures (duo physesin)[56] understood in the abstract sense. Recently, however, there has been a more open attitude toward the mia physis formula especially in the Eastern Orthodox churches.[57] As we have alreadv suggested, the issue largely depends on the sense in which the words are taken. From the viewpoint of complementarity Christ must be described as one single being whether as prosopon, hypostasis, physis or (prote) ousia.

(2) Common Properties: Just as in the doctrine of the Trinity the homoousion does double duty by asserting a common substance as well as a single being, in Christology

the hypostatic union implies both a single person and a common subsistence. And just as the common properties which are in the Father are the source of those with which the Son is endowed,[58] the preexistent subsistence of the Logos is the source of the subsistence of his assumed humanity (enhypostasia), that humanity having no independent subsistence of its own (anhypostasia).[59] Apparently, however, this common subsistence does not entail a common will (thelema) or a common operation (energia);[60] these must therefore be classified as "conjugate properties" (see point 9 below).

(3) Individual Completeness: Each of the "natures" or "modes of being"[61] in Christ is complete, entire, perfect and fully real in itself (if not of itself due to the (enhypostasia).[62] It follows that Christ is both homoousion to patri and homoousion hemin[63] although the latter point is somewhat problematic. It certainly means that the humanity Christ assumed was a full humanity, composed of both body and soul.[64] But there is also a strong soteriological tradition running from Hilary to Barth which maintains that Christ's incarnation and resurrection pertain not just to his individual humanity but to mankind as a whole.[65] On the basis of our previous discussions, I can see two possible explanations for this amazing claim: it could be regarded either diachronically as a statement of Christ's 'recapitulation' or 'summing up' of man's history,[66] or else synchronically as a special case of the mirroring or imaging of all mankind in each individual man.[67] Perhaps both explanations are required: the synchronic view shows how it is possible for any one individual to represent all men, and the diachronic

view shows how it came to be that this one man, Jesus Christ, did represent all men. Either view would then be incomplete by itself and would require the other for its elucidation.

(4/5) Coexhaustiveness and Equal Necessity: There are two natures or modes in Christ, no more and no less. The two are equally real and equally true.[68] "He does not cease to be God because He becomes man [against Kenoticism], nor fail to be man because He remains for ever God [against Docetism]. This is the true faith for human blessedness, to preach at once the Godhood and the manhood, to confess the Word and the flesh, neither forgetting the God, because He is man, nor ignoring the flesh, because He is the Word."[69] It follows that both modes must be included in any treatment of the person of Christ and that neither one can be eliminated in favor of the other.

(6) Alternation: Since time itself, in our view, is an ongoing dialectic between God and the world,[70] the life of Christ must entail a continual alternation between its own two modes. This does not mean that the Logos is changed into flesh or *vice versa*, as Tertullian points out,[71] because the Word was made flesh by clothing rather than by transformation. Nor does it mean that the acts and words of Jesus can be divided into two categories, human and divine,[72] for all of the visible-audible activity of Christ was performed by the Word-made-flesh.[73] The properly divine activity of Christ is his sustaining and governing of all creation,[74] but this is not visible or audible; it is only known tacitly and by grace.[75] According to Maximus the Confessor,[76] the two natures and their activities reciprocate or alternate with one another like thought and word or like

the reciprocal actions of cutting and burning by a red-hot knife. Or, as John of Damascus puts it,[77] there are two reciprocal movements, the deification (theosis) of the flesh and the "inhomination" (enanthropesis) of God. From the alternation of the natures, we then come to their mutual interpenetration.

(7) Coinherence: Implicit in the very fact of incarnation is the fact that the Logos indwells or inhabits the flesh like a garment or a temple.[78] There follows a reciprocal penetration of the humanity into the (immanent) deity of the Logos so that there is a mutual penetration (perichoresis) and coinherence between the two natures.[79] Hence, where one nature is present the other is also, and what one nature does (or what Christ does in and through that nature) the other does also so that there is an inter-participation and "co-operation" between the two.[80] Then, on account of this perichoresis and in view of the hypostatic union, the Fathers argue,[81] there is an interchange of titles, functions and attributes (antidosis idiomaton) between the two natures. But what is the nature of this interchange? It cannot be a mere matter of words as Nestorius[82] held or only a figure of speech as Zwingli[83] claimed. On the other hand, it must not be allowed to obliterate the distinctive characteristics of Christ's humanity as it does in Gregory of Nyssa[84] or even Hilary.[85] Perhaps Calvin's rather ambiguous attitude is most appropriate here; the transfer of attributes is done improperly though not without reason![86]

(8) Mutual Exclusiveness: In spite of their interpenetration the two natures or modes of being remain unconfused (asunkutos) and unchanged (atreptos), each retaining its full integrity within the hypostatic union.[87] This is due to the fact that they are mutually exclusive, i.e. "incongruous" and "utterly dissimilar" to begin with[88] so that no compromise or reduction to an intermediate nature or mode is even conceivable.[89]

(9) Conjugate Properties - Reciprocity: Each of the two natures or modes of being has its own proper functions and attributes, and these remain intact within the hypostatic union;[90] even Cyril of Alexandria agrees to this point.[91] The conjugate functions and attributes include being "in heaven" vs. being "on earth",[92] sustaining the universe vs. living a human life,[93] being uncreated vs. created, invisible vs. visible, unconfined vs. confined,[94] and even two natural volitions, two natural energies, and two kinds of wisdom and knowledge.[95] Moreover, there is a definite relation of reciprocity between these conjugate properties in that the attributes proper to one mode are inappropriate to (hence not strictly definable in) the other mode.[96] This principle naturally counterbalances the antidosis idiomaton, but it applies only to the opposition of properly human and properly divine activities and should not be confused with an artificial division of Christ's human life into two parts corresponding to the humanity (i.e. the moments of weakness and humiliation) and divinity (the miracles and the resurrection).[97]

(10/11) Emergence and Pointing: The point here is simply that the two natures or modes of being are not symmetric to each other but involve two different "levels" of reality: one is "higher" while the other is "lower"; one is "in heaven" while the other is "on earth".[98] Moreover, the human nature <u>depends upon</u> the divine nature as its source of life and subsistence,[99] and, accordingly, it <u>points to</u> that source as a true manifestation or revelation of God.[100] In this sense Christ's humanity is indeed an instrument (<u>organon</u>) through which he makes himself known as Athanasius said.[101]

The foregoing analysis speaks for itself: there is clearly a one-to-one relation between the major points of Christology and the eleven points of complementarity, and the logical relationships among the former are identical to those among the latter. It should be noted, however, that the diachronic dimension is much more important in Christology than in any of the natural sciences, and it is not accounted for (though it is allowed for) in the synchronic model of complementarity. Moreover, the point of coinherence which was almost incidental in quantum physics has become a major principle in theology.

Footnotes: Chapter 10

1. esp. Irenaeus, Tillich (The Interpretation of History), Cullmann (Christ and Time), and Pannenberg (Jesus-God and Man, London, 1968).

2. esp. Athanasius, Barth (Church Dogmatics), Brunner (The Mediator, London, 1934), and Torrance (Space, Time and Incarnation, London, 1969).

3. Compare T.F.Torrance's view of the "twofold reference" of the apostolic witness, vertically to (the risen and exalted) Christ and horizontally, on the plane of history, to us (Theology in Reconstruction, p.43). The terms 'synchronic' and 'diachronic' were popularized by de Saussure (op.cit., p.86).

4. H.R.Mackintosh, The Doctrine of the Person of Jesus Christ, Edinburgh, 1913, p.240.

5. Thus Pannenberg's distinction between the historical dependence of Jesus on the Father and the "ontological dependence of the whole of Jesus' human existence on the person of the Logos" (Jesus-God and Man, pp.338f).

6. "What is true in God's eternity is decided with retroactive validity /rückwirkende Kraft/ only from the perspective of what occurs temporally with the import of the ultimate." (ibid, p.321).

7. "...Jesus' resurrection is the basis for the perception of his divinity..." (ibid, p.108).

8. "Apart from Jesus' resurrection, it would not be true that from the very beginning of his earthly way God was one with this man. That is true from all eternity because of Jesus' resurrection." (ibid, p.321).

9. ibid, p.322.

10. The idea of the "retroactive effect" of the Incarnation on the history of Israel had previously been suggested by J.McIntyre, The Christian Doctrine of History, p.91.

11. Hence the ambiguity of Jesus' earthly conduct (especially in relation to the Jewish law) and of his dedication to the Father is only resolved by the resurrection; ibid, pp.362f.

12. i.e. the "Gnostic redeemer myth" to which Barth comes so close in Pannenberg's view; ibid, pp.33f.

13. "Only the occurrence of what is ultimate, no longer superseded, is capable of so qualifying that whole of the course of time, beyond the moment of its own occurrence,

that it can be strictly conceived as true (permanent) in eternity and thus as united with God's eternity." (ibid, p.321, fn.96).

14. cf. D.M.Baillie, God Was in Christ, New York, 1948, pp. 200f.

15. G.C.O'Collins, "The Christology of Wolfhart Pannenberg", Rel.Stud. 3, 1967, p.376.

16. Barth: "This [one personal] God as such is the Subject of the incarnation... But He is this in His mode of being as Son, and not as the Father or the Holy Spirit." (Church Dogmatics IV.2, Edinburgh, 1958, p.44); Rahner: "Jesus is not simply God in general, but the Son." (The Trinity, p.23); cf. John of Damascus, De Fid.Orth. 3.11,4.4.

17. See above, p.92.

18. See above, p.251, esp. fn.21.

19. The Mystical Theology of the Eastern Church, p.138.

20. De Inc. 8,17,43; cf. Calvin, Inst. 2.13.4.

21. De Inc. 8.

22. "Thus He ensured that men should recognize Him in the part who could not do so in the whole, and that those who could not lift their eyes to His unseen power might recognize and behold Him in the likeness of themselves." De Inc. 43 (E.T. On the Incarnation, London, 1953, p.79).

23. cf. above, p.300.

24. See H.de Riedmatten, Les Actes du Procès de Paul de Samosate, Fribourg, 1952, S 6,8,9,10,39.

25. i.e. in a "ladder of theophanies" or the "ladder of cataphatic theology...a series of steps up which the soul can mount to contemplation." V.Lossky, op.cit., pp.40f.

26. Or.con.Ar.3.53; cf.3.31,35, and De Inc.8,9,43,44 (see comment in Select Treatises of S.Athanasius in Controversy with the Arians, Oxford, 1844, p.443, note g).

27. De Inc. 8.

28. De Inc. 44, Or.con.Ar. 3.33; cf. Gregory of Nazianzus, Ep.101.11.

29. Or.con.Ar. 3.30,31. In the terminology of Lutheran theology Athanasius is here teaching a genus tapeinoticum in Christ in contrast to the mere genus majestaticum of theophany! This involves no contradiction with the "immutability" of God's essence if the Incarnation pertains directly to the energies as found in (2) above.

30. According to the Fathers the Incarnation (i.e. the unitio personalis) entailed Christ's humiliation (Athanasius, Or.con.Ar. 3.30; Hilary, De Trin. 9.6), but the latter was distinct from the result of the Incarnation (the unio personalis) which was permanent and not reversed even by the resurrection and exaltation (Athanasius, Or.con.Ar. 1.42,45; Hilary, De Trin. 9.6; contra Origen, Con.Cels. 2.62, In Jer.Hom. 15.6; and Gregory of Nyssa, Ant.adv.Apol. 25, Con.Eunom. 5). Theologians in the Reformed tradition have tended to treat the humiliation as a mere veiling by the flesh (e.g. Calvin, Inst.2.13.2) or a participation in the human sphere (Barth, Dogmatics IV.2, pp.64f,69) and are justly criticized by Lutherans for equating the doctrine of humiliation and exaltation with the doctrine of the two natures (e.g. Pannenberg, op.cit., p.33). However, the latter are themselves in danger of excluding the element of humiliation and scandal from the Incarnation altogether and thus undoing the unified vision of Athanasius (see e.g. Bonhoeffer, Christology, London, 1966, p.47: "The doctrine of the scandalon has its place not in the doctrine of the Incarnation of God but in the doctrine of the state of humiliation of the God-man.").

31. cf. pp.294ff above.

32. J.H.Leith, ed., Creeds of the Church, New York, 1963, p.33.

33. cf. above, pp.301,303.

34. e.g. the descent of the Buddha from the Tushita heaven; see G.Parrinder, Avatar and Incarnation, London, 1970, pp.133ff.

35. Hilary, De Trin. 9.4,10.16; Leo the Great, Ep. 28(Dogmatica ad Flavianum).4; Calvin, Inst. 2.13.4.

36. See ch.3.3. above.

37. i.e. Father and Son (above, p.248, fn.13), God and the world (p.270, fn.10), and heaven and earth (p.306, fn.65).

38. e.g. Gregory of Nazianzus, Ep.101; Gregory of Nyssa, Ant. adv.Apol. 2, Or.Cat. 10,11; Augustine, Enchir.11.36, Ep.137.3.11, In Johan.19.15, Sermo.186.1.1; for further citations see H.A.Wolfson, op.cit., pp.368f.

39. Theodoret of Cyrus, Eran.2.

40. Cyril of Alexandria, Adv.Nest. 2pref., Ep.45,46, Schol. de Inc.9.

41. Church Dogmatics IV.2, p.54. Barth's point is that the soul depends upon the body for its life whereas the Logos assumes humanity and gives it existence. This point is included in Wolfson's first objection listed below.

42. H.A.Wolfson, _op.cit._, pp.429ff.

43. One of the four basic ideas in the overall logic of complementarity; see above, pp.109f.

44. See pp.239f. above.

45. See pp.107f above.

46. See p.282 above.

47. On the relation between the two wills in Christ see Origen, _De Princ_.2.6.5 (Christ's preexistent soul chose righteousness with such love and firmness of purpose that it destroyed all susceptibility for change and became incapable of sin); Gregory of Nazianzus, _Or_.30.12 and Gregory of Nyssa, _Ant.adv.Apol_.32 (the human will did _not_ completely conform to the divine will, but struggled and wrestled against it!); and the Third Council of Constantinople ("his human will following, and not resisting or opposing, but rather subject to his divine and all-powerful will." J.H.Leith, ed., _op.cit._, p.51).

48. See above, pp.108f and (for the individuality of organisms in general) 158f.

49. See above, p.256.

50. This was not brought out explicitly in chapter 8, but see p.240 on the uniqueness of God and the universe and its bearing on the definition of their modality.

51. See G.L.Prestige, _God In Patristic Thought_, pp.270ff; and J.McIntyre, _The Shape of Christology_, pp.86ff.

52. Nestorius, Fragment 198 (F.Loofs, _Nestoriana_, Halle, 1905, p.224); Theodore of Mopsuestia, _De Inc_.8; Theodoret of Cyrus, _Ep_.104.

53. Nestorius, quoted by Cyril of Alexandria, _Adv.Nest_. 2pref., 2.2; and Theodore of Mopsuestia, _De Inc_.7.8.

54. Cyril of Alexandria, _Adv.Nest_. 2pref., 2.2.

55. Apollinarius, _Pros Iobianon_ 1 (H.Lietzmann, _Apollinaris von Laodicea und seine Schule_, Tübingen, 1904, p.251); Cyril of Alexandria, _Adv.Nest_. 2pref., _Ep_.46 (_ad Succensum_).2. For a recent statement of the Monophysite position see W.A.Girgis (now Bishop Gregorius), _The Christological Teaching of the Non-Chalcedonian Churches_, Cairo, n.d.

56. The Definition of Chalcedon.

57. See A.S.Atiya, _A History of Eastern Christianity_, London, 1968, p.447.

58. See above, pp.254f, 277f.

59. Leontius of Byzantium, Con.Nest. et Eut.; Leontius of Jerusalem, Con.Nest. 2.13; Epiphanius, Adv.Haer.Pan. 77. 33, Expos.Fid. 15; John of Damascus, De Fid.Orth. 3.9. Note that Christ does not differ from other men in being enhypostatic for all men depend on God for their entire being (cf. p.277 above). The difference is simply that between Christology and general providence discussed above in section 2(3).

60. So the Third Council of Constantinople in 681; cf. John of Damascus, De Fid.Orth. 3.13.

61. For the use of tropos huparxeos in this sense see Leontius of Byzantium, Con.Nest. et Eut. prol., 1 (see G.L.Prestige, op.cit., p.248).

62. Hilary, De Trin. 9.3,9.6,10.19,11.6; Leo the Great, Ep. 28.3 (totus in suis, totus in nostris), and the Definition of Chalcedon.

63. Symbol of Union (433), and the Definition of Chalcedon (451).

64. Theodore of Mopsuestia, Hom.Cat. 5.19.

65. Hilary, De Trin. 2.24; Gregory of Nazianzus, Ep. 101,4; Gregory of Nyssa, Con.Eunom.12.1; John of Damascus, De Fid.Orth. 3.3,3.6, K.Barth, Church Dogmatics, IV.2, p.59.

66. Irenaeus, Adv.Haer.3.16.6,18.1,18.7,21.10,22,3; cf. O. Cullmann, Christ and Time; and above, p.318, esp. fn.1.

67. See above, p.108f.

68. Athanasius, Or.con.Ar.2.70; Hilary, De Trin.9.3,10.22.

69. Hilary, De Trin.9.3 (E.T., p.156).

70. See above, pp.279f.

71. Adv.Prax. 27; cf. the Definition of Chalcedon (atreptos); contra Gregory of Nyssa, Con.Eunom.5.5.

72. As is done e.g. by John Chrysostom (In Quat.Laz.1) and Ambrose (De Fide 2.77).

73. Hilary, De Trin. 10.26.

74. Athanasius, De Inc. 17; see above, section 2(3).

75. See above, pp.238f.

76. Disp.cum Pyr.187A, Opusc.102B; see G.L.Prestige, op.cit., pp.293f.

77. De Fid.Orth. 3.17; cf. pseudo-Cyril, De Sac.Trin. 24: "...the divine nature having once penetrated through (dia) the flesh, bestows on the flesh an ineffable penetration with (pros) itself..." (E.T., H.A.Wolfson, op. cit., p.423).

78. John 1.14 (eskenosen en hemin); Athanasius, De Inc.8,9, 20, Or.con.Ar.3.52; Hilary, De Trin.10.26; Theodore of Mopsuestia, Hom.Cat.7.1,8.5; and the early Cyril of Alexandria, Thes.23,24,28; contra the later Cyril, Ep. 17.4 (see J.Quasten, Patrology, Vol.3, pp.137-139).

79. Gregory of Nazianzus, Ep.101.87C; Gregory of Nyssa, Con. Eunom.1.95; pseudo-Cyril, De Sac.Trin.22,24; Maximus the Confessor, Amb.Lib.112bD, Ep.4.8; John of Damascus, De Fid.Orth.3.3,3.8,4.3.

80. Tertullian, Adv.Prax.27 ("...he comes to be in flesh, and is manifested and seen and handled by means of the flesh." E.T., Treatise Against Praxeas, London, 1948, p.173); Hilary, De Trin.9.5 ("man saying and doing all that belongs to God; God saying and doing all that belongs to man." E.T., p.156); Augustine, De Trin.1.13.28 (the Lord of Glory crucified, 1 Cor.2.8; the Son of Man will come in glory, Mt.25.31). Note that these statements are direct parallels to Bohr's statements about the "motion of a particle" in free space and "waves passing through the slit" (see above, pp.60f). The vagueness of terms like coinherence and interpenetration should not obscure the parallel.

81. Gregory of Nyssa, Con.Eunom.5.5 ("because of the conjunction and connexion the attributes of each nature become common to both"; E.T., H.Bettenson, op.cit.lp.138); pseudo-Cyril, De Sac.Trin.27 ("each nature interchanges with the other its peculiar properties, through the identity of hypostasis and their penetration into one another." E.T., H.A.Wolfson, op.cit., p.422); cf. John of Damascus, De Fid.Orth.3.3,3.4; this line of reasoning was explicitly rejected by Tertullian, Adv.Prax.27. Contrast the argument from coinherence to unity in the doctrine of the Trinity (see above, p.253).

82. Fragment 78 (F.Loofs, Nestoriana, pp.217f).

83. cf. the Formula of Concord, Epitome, Art.8, Neg.7; see T.G.Tappert, ed., The Book of Concord, Philadelphia, 1959, p.490.

84. Con.Eunom.5.5.

85. De Trin.10.23,24 (not an ordinary human body, not susceptible to pain, not overwhelmed by passion; he conformed to custom, not to necessity).

86. "...the things that he carried out in his human nature are transferred improperly, although not without reason, to his divinity." Inst.2.14.2 (E.T., Institutes of the

Christian Religion, Philadelphia, 1960, Vol.1, p.484); cf. section 2(4) above on the importance of humiliation in the Incarnation. From the diachronic viewpoint there is a real antidosis and even a kenosis, but this should not be confused with the synchronic relation between the two natures.

87. Didymus the Blind, De Trin.2.8,3.6; Definition of Chalcedon.

88. Hilary, De Trin.9.14 (incongruous), and 10.22 (two contraries); Cyril of Alexandria, Adv.Nest.2.6 ("...there is a very great difference, indeed the greatest disparity, between divinity and humanity: these terms clearly denote things essentially diverse and utterly dissimilar." E.T., H.Bettenson, op.cit., p.253).

89. Tertullian, Adv.Prax.27 (no amalgam of man and God); pseudo-Cyril, De Sac.Trin.24 (impossible for two contraries to be changed into a single composite nature).

90. Tertullian, Adv.Prax.27 (in statu suo); Gregory of Nyssa, Con.Eunom.6.1; Theodoret of Cyrus, Eran.2; Leo the Great, Ep.28.2-4.

91. Ep.40,46.

92. Hilary, De Trin.10.16; cf. section 2(5) above.

93. Athanasius, De Inc.17.

94. Gregory of Nazianzus, Ep.101.4, Or.37.2,38.13.

95. John of Damascus, De Fid.Orth.3.13; Third Council of Constantinople (681).

96. Athanasius, Ep.ad Serap.4.14; Gregory of Nyssa, Con. Eunom.6.1; cf. above, p.64.

97. See above, fn.72.

98. Hilary, De Trin.9.4,10.16.

99. Athanasius, De Inc.17; cf. section 3(2) above.

100. Athanasius, De Inc.17,18, Or.con.Ar.3.53; cf. above, pp.237ff.

101. De Inc.8. Hence we can only partly agree with Bonhoeffer when he says, "One does not first look at a human nature and then beyond it to a divine nature; one meets the one man Jesus Christ, who is fully God." (Christology, p.108). It is true that one never looks beyond the human nature, for the divine nature inheres within it, but one can never perceive that divinity so long as one knows Christ only specifiably. Hence one must allow the humanity to point "beyond" itself and learn to know (the same) Christ in accordance with his own proper and unique function as the Son of God (Mt.16.16).

Chapter 11

The Church, Word and Sacraments

"For if in truth the Word has been made flesh and we in very truth receive the Word made flesh as food from the Lord, are we not bound to believe that He abides in us naturally [naturaliter], Who, born as a man, has assumed the nature of our flesh now inseparable from Himself, and has conjoined the nature of His own flesh to the nature of the eternal Godhead in the sacrament by which His flesh is communicated to us? For so are we all one, because the Father is in Christ and Christ is in us."
Hilary, On the Trinity 8.13 (p.141).

11.1 Introduction - Ecclesiology in Perspective:

In this final chapter on the application of complementarity to theological issues we consider the nature of the church, the word of scripture and of proclamation, and the sacraments of baptism and the eucharist. Each of these is, of course, a topic in itself, but for our purposes they may be treated together and, in fact, are best treated together due to their structural similarity and interrelation.[1] In each case there is a multi-polar relation between the risen Christ in heaven, the Holy Spirit, and the visible elements on earth through which they operate in the history of the church during this present age.

By setting the problem up in this way I intend specifically to exclude any consideration of an "invisible church" in heaven which is related in some fashion to the "visible church" here below.[2] This model seems to have been derived from an archaic two-level cosmology in which everything was either sensible (e.g. our bodies, 'earth') or intelligible (e.g. our souls, 'heaven', eternal 'ideas', God) with the result that the spiritual side of man and of the church was regarded as existing on the same level as heaven and even God.[3] Clearly, such a model is not compatible with the biblical view of man as earthbound (at least during this life) and of God as transcending even heaven itself (2 Chron.6.18).

Hence the earthly, 'empirical' side of the church is man, himself, in his fullness - body and soul, atom and organism, wave and particle. The 'transcendent', heavenly side is rather more complicated; it involves not only the triune structure of (the immanent) God but also the complementarity of creator and creature involved in the being of the Word-made-flesh. Since we have already worked through the various combinations and permutations of these terms (Word-Spirit, creator-creature, heaven-earth) in previous chapters, we may put the matter succinctly by saying that the relation between the Holy Spirit and man in the church is modelled along the lines of theophany - a simple creator (Spirit)-creature relationship with the function of historical revelation and redemption. Thus the church is said to be the "temple of the Spirit", the word is inspired by the Spirit (here through apostles, evangelists and preachers rather than O.T. prophets), and the administration of baptism and the consecration of the elements in the eucharist are accompanied by and activated by the Spirit. From the strictly synchronic viewpoint these activities of the Spirit in the church are identical to those in the Old Testament - theophany, prophesy and miracle. The only difference between them is the diachronic or historical one due to the watershed-event of the Incarnation.

The relationship of Christ and man in the church is quite different since the Word, unlike the Spirit, was the actual subject of the Incarnation and is forevermore the Word-made-flesh. Our union with Christ, then, is not simply a theophany, even in the strictly synchronic sense for we are not joined to a disembodied Word, as were the prophets,[4] but in the first instance to the humanity of Christ which is now glorified in heaven. We are his 'body' not because he is the mind or the soul but because he is the 'head'. Hence we are one body (and one soul) with him as well as with one another.[5] The relation of Christ and the church, then, must be considered at two levels: (1) the relation of the Word to his 'flesh', both in heaven and on earth, which is parallel to the relation of creator and creature in theophany, and (2) the intracosmic relation between the heavenly 'head' and his earthly 'body', i.e. between Christ's glorified humanity and us, which is parallel to the intracosmic relation of heaven and earth as in the case of angels.[6]

There is an asymmetry, then, between Word (made flesh) and Spirit in ecclesiology that is not present in the supra-historical intra-trinitarian relations (even granting the <u>filioque</u>) and is not present in Old Testament redemptive history. In the liturgical traditions this asymmetry is possibly reflected in the difference between the <u>epiklesis</u> and the <u>anamnesis</u>: the Holy Spirit is 'invoked' as one from beyond, at least in the Eastern tradition, while the Incarnate Word is simply 'remembered' as one who already resides within the intracosmic sphere.[7]

11.2 Mystical Union, Sacramental Union and Transubstantiation:

It would simply be tedious to try to document all eleven points of complementarity for the nature of the church, the word and each of the sacraments, and little would be added to the overall picture we have already built up in previous chapters. The relations of creator and creature and of heaven and earth have already been investigated in detail under separate headings, and one can easily document the necessary analogies between the relation of Christ (or the Spirit) and the church and the relations of Father and Son in the Trinity,[8] of Word and flesh in the Incarnation,[9] and of body and soul in man.[10] Therefore, we may concentrate our attention on the two most problematic (and therefore most interesting) points, the nature of the 'union' in church, word and sacraments and the manner in which this union is achieved, which correspond to the first two points in the logic of complementarity.

First, with regard to the church we must say three things in light of the foregoing discussion: (1) Christ and his 'body' are one person (hypostasis) or one being,[11] (2) his glorified humanity and our humanity are one 'body',[12] and (3) the Holy Spirit and ourselves constitute one life and one 'spirit'.[13] For instance, the mystical union of Christ's humanity and the church is compared by Hilary to the essential union of Christ's deity and the Father; both are said to exist 'naturally' (naturaliter), i.e. by virtue of a common 'nature' (here in the sense of prote ousia since it is effected by the reception of the sacraments as well as the occurrence of the Incarnation).[14] It follows that, since the union of Christ and the church is as real as that between Father and Son, those properties which are common to both (head and body) must have their source in the ontologically prior mode (the head).[15] In other words, the church - as church (the body of Christ) - must be 'enhypostatized' in the glorified humanity of Christ (which, in turn, is 'enhypostatized' in the deity of Christ) which is the source of its specifically Christian life, its holiness and its very being-as-church, its catholicity.[16]

Similar considerations could be developed, with suitable adaptions, for the union of the word of man and the Word of God in inspiration and proclamation.[17] It should be noted that this 'verbal union' both presupposes the 'mystical union' in the church (here between Christ and the listener as well as between Christ and the speaker) and, at the same time, reinforces it through the 'hearing' of the Word. Hence there is a dialectic of word and church which allows a progressive strengthening of the 'mystical union' and rules out the kind of timeless transcendentalism usually associated with 'epiphany religions'.[18] Of course, the same progressive dialectic holds between the sacraments and the church: the minister consecrates and administers or distributes the elements as the representative of Christ,[19] and this mystical union is strengthened through the 'worthy reception' of those elements.[20] Finally, there is also the dialectic of word and sacrament: the word explains and sanctifies the sacrament;[21] the sacrament illustrates and confirms the word.[22]

In the case of the sacraments we again have a kind of union (a) between the Holy Spirit and the water in baptism, and (b) between the glorified body of Christ and the consecrated elements of bread and wine in the eucharist. In regard to baptism, of course, there is the perennial question of the relation between baptism with water and baptism with the Spirit, but this is really a diachronic problem and need not detain us here. If we may draw a parallel with the problem of the Incarnation and its relation to the Resurrection, we may say that the Spirit is in and with the waters of baptism independently of the subsequent development of the person being baptized even though the character of the Spirit's activity in and with the baptismal waters may be decided retroactively on the basis of such development.[23] At least, there is no doubt in the minds of the Fathers, that by virtue of the <u>epiklesis</u>, the baptismal waters are truly united with the Spirit who acts in and through them.[24] Moreover, it follows that, insofar as the waters have any grace or efficacy, they derive it not from their own nature but from the presence of the Spirit.[25] In this sense they may be said to be 'enhypostatized' in the Spirit.

In regard to the eucharist the problem is complicated by the fact that there are at least three different traditions in Western theology, the Catholic view of transubstantiation, the Lutheran view of sacramental union or consubstantiation, and the Reformed view of sacramental conjunction. The difference between the Catholic and Lutheran views seems to boil down to a difference of terminology.

The Latin word _substantia_, like the Greek _ousia_ (and, unfortunately, the German _Wesen_), can be used in the sense of either primary or secondary substance. The medieval church evidentally understood it in the primary sense (i.e. concrete, independent reality), hence the use of the Aristotelian distinction between 'substance' and 'accidents' or 'species' (= _substantia secunda_), as Schillebeeckx has recently pointed out.[26] Since there can only be a single primary substance within the sacramental (or any real) union and since Christ is a primary substance in his own right, the elements of bread and wine must be de-substantiated or dispossessed of their independent reality and trans-substantiated or possessed from above by the independent reality of Christ.[27] Clearly, there is a parallel here with the _anhypostasia_ and _enhypostasia_ of Christ's humanity itself. In fact, the dynamics of transubstantiation are simply the reflex action of the _enhypostasia_ at a lower level: (1) Christ's (glorified) humanity is enhypostatized in the divine hypostasis, and (2) the elements of bread and wine are enhypostatized (transubstantiated) in the enhypostatic humanity of Christ. There is this difference, however; the elements of bread and wine are preexistent ("Christ _took_ bread and wine...") whereas the humanity of Christ was not ("the Word _became_ flesh"). Hence the force of the prefix _trans_ and all of the suspicions that it naturally raises.

Luther, on the other hand, seems to have understood _substantia_ in the secondary sense although it is difficult to get a consistent picture out of his various writings. Sometimes he spoke of the bread and the body of Christ uniting to form an entirely new substance (Wesen) or thing (Ding),[28] a view which would seem to require some sort of transsubstantiation! More often, however, he took the opposite tack, claiming that the sacramental union, like the personal union of Christ, consists of two distinct natures or substances although these may be called one substance or one thing by way of synecdoche.[29] On these terms the notion of transubstantiation was not only unnecessary; it would have been totally inappropriate since it would have denied the full reality of the elements of bread and wine and thus undermined the significance and value of creation.

As Calvin was quick to point out, however, Luther's view of 'con-substantiation' implies an unacceptable duality in Christ's body.[30] In other words, either Christ's body and the elements are truly united to form one thing, in which case a doctrine of transubstantiation seems inevitable, or else there are really two things which interact or are conjoined in some way.[31] Needless to say, complementarity could not be used as a model in the latter case; hence it could have no place in a Reformed view of the sacraments, at least, as traditionally conceived.

11.3 'Ecstasy' and 'Enthusiasm':

In this and the previous two chapters we have concentrated on the ontology of complementarity, the various relations between creator and creature, heaven and earth, which correspond with the religious phenomenon of 'enthusiasm' or 'possession', the state of a man in whom God dwells and through whom God speaks and acts.[32] The similarity and dissimilarity between the general religious phenomenon and the biblical view of theophany have already been discussed in chapter 9.2. In this final section I would like to return to the problem of man and his ability to know which was raised in chapter 1.5 and again in 3.3. After all, perhaps the most astounding feature of our world is not that modal alternations are continually taking place whether we are aware of them or not, but that man is actually able to discern them, i.e. to extend the limits of his subjecthood and indwell objects that are external to his own body and thus to follow the shifts in the "subject-object boundary" at various levels.[33] In keeping with the language of religious phenomenology we may refer to this extension of subjecthood as a movement of 'ecstasy'. Then the question naturally arises; just what is the relationship between 'ecstasy' and 'enthusiasm' in Christian theology?[34]

Specifically, in regard to the word and the sacraments, we have a problem of worthy reception. In spite of the real presence of God in word and sacrament, we are continually reminded by theologians of all ages that faith is necessary if we are to benefit from this presence.[35] We must "lift up our eyes" to heaven in order to discern the presence of Christ.[36] What does this mean? What does it mean to hear the word of God or to taste the flesh of Christ? It means to apprehend them <u>in accordance with their proper function</u>. Of course, a string of words or a piece of bread can function on many different levels at once. There are the atomic and molecular levels (even words can be analyzed into vibrations in the air or else molecules of ink on paper), the various organismic levels, and then the specifically human level of artifacts and ideas. Bread, for instance, is an artifact with a particular social and religious significance in each culture (at least in western Asia and Europe). But when bread is consecrated in the eucharist it begins to function at an entirely new level, viz. as the body of Christ. This is not the replacement of one function by another ('trans-functionalization') at the cultural level, as Schillebeeckx would have it,[37] for the bread continues to have its usual social and religious significance, or, at least, it should. Rather, the bread, together with its cultural significance, operates in relation to the body of Christ just as the bread alone operates in relation to its cultural significance at a somewhat lower level.[38]

Naturally, the same considerations apply to the words of scripture or to the waters of baptism. Then, to hear the word or receive the sacraments "worthily" is to understand their proper (i.e. specifically Christian) function and to apprehend them accordingly. Thus, it is not so much the entry of words into the ear or of bread into the mouth that benefits us as the extension of our subjecthood outward to indwell word and sacrament as they are. One receives these gifts of God not so much by consumption as by appreciation, not so much by taking bread as by giving thanks. This is the specifically Christian sense of the term 'ecstasy'.

It should also be clear, then, that this Christian form of 'ecstasy' requires and presupposes a Christian form of 'enthusiasm'. As we noted in chapter 6.5, man's ability to control modal alternations extends only as far as the level of man. It follows that man's natural ability to recognize modal alternations should also only extend as far as the human level. In fact, it is a general rule that beings can only recognize other beings and phenomena that do not exceed their own level of being. Animals can recognize each other and can recognize man as another animal, but they cannot recognize the presence of mind or appreciate the force of ideas or the beauty of art. So a man can recognize another man, as a man, but how can he recognize another man as the Son of God (Mt.16.17) or another man's words as the Word of God? How can he give thanks for the gift of Christ's flesh and blood in the sacrament? How can he have the proper faith? Certainly he must be 'born again' into a higher level of existence (Jn.3.3); not that he evolves from below into a higher order of being himself; rather he is 'born from above' as he enters into complementarity with the incarnate Word of God, is dispossessed of his own independent being and is "trans-substantiated" or repossessed by by the Word-made-flesh. It is only by virtue of this Christian 'enthusiasm', viz. Christ-in-us, that we are able to extend our subjecthood to indwell the word and sacraments in accordance with their properly Christian function.[39] 'Enthusiasm' is the necessary condition for 'ecstasy', and this 'ecstasy', in turn, reinforces the 'enthusiasm' on which it is based.

These considerations finally provide us with the theological underpinning of the logic of complementarity.

In chapter 1.5 we began with the structure of man's knowing and from that we inferred the structure of being which it required as its presupposition. We have also noted in passing that man's knowing must somehow be modelled on the structure of being as a general rule,[40] but here, at last, we can actually see how man's ability to know, even beyond his own level, is grounded in the structure of his relationship beyond his own level, to God.

Footnotes: Chapter 11

1. See Bonhoeffer, Christology, pp.47,49.

2. This notion goes back to Clement of Alexandria (Strom. 4.8.66,6.14.108) and Origen (De Orat. 20.1). It has come down to us through Augustine (e.g. De Civ.Dei 10.6) and Calvin (Inst. 4.17) and has recently been taken up by Hans Küng in his study, The Church (London, 1968, pp. 34-39).

3. One consequence of this notion was the belief that in baptism man's soul is cleansed by the Holy Spirit while his body is washed with water and, similarly, that in the eucharist man's soul feeds on the 'spiritual' body of Christ while he eats the bread with his mouth; e.g. Irenaeus, Adv.Haer.3.17.2; Tertullian, De Res.Car. 8; Cyril of Jerusalem, Cat.3.4; Calvin, Inst.4.15.4,4.17. 1,10,24.

4. A point stressed by Bonhoeffer (Christology, p.55).

5. Athanasius, Or.con.Ar.3.22; Cyril of Alexandria, Com.in Johan.17.21; Luther (see E.M.Plass, ed., What Luther Says, Saint Louis, 1959, p.274, no.806); Calvin, Inst. 3.11.10.

6. See above, ch.9.1.

7. See J.-J.von Allmen's valuable studies, Worship: Its Theology and Practice (London, 1965, ch.1.2-3) and The Lord's Supper (London, 1969, ch.1).

8. e.g. Hilary, De Trin.8.13; cf. V.Lossky, The Mystical Theology of the Eastern Church, p.87.

9. e.g. Ignatius, Epistles to the Ephesians (10.3), Magnesians (13), and Smyrnaeans (12.2); cf. K.Rahner, Studies in Modern Theology (London, 1964, p.201).

10. e.g. Origen, Con.Cels.6.48f; Augustine, Sermo.267.4, 268.2. N.B. so long as this is only an analogy (of proportionality) it is valid, but it must never become an equation; cf. fn.3 above.

11. Augustine, Enar.1 in Ps.30.4 (una quaedam persona).

12. See fn.5 above.

13. Cyril of Alexandria, Com.in Johan.17.21f.

14. Hilary, De Trin. 8.13,15.

15. See above, pp.254,277,328. The common properties in

question here are, of course, the specifically Christian ones associated with being-in-Christ and are not to be confused with the common properties associated with mere being-as-such in the doctrine of creation. The difference between them is synchronic (structural) as well as diachronic (historical) due to the Incarnation.

16. "...as a soul vivifies and moves the body, which of itself has not the natural power of motion like a living being, so the Word, arousing and moving the whole body, the Church, to befitting action, awakens, moreover, each individual member belonging to the Church, so that they do nothing apart from the Word." Origen, Con.Cels.6.48 (E.T., J.Quasten, Patrology, Vol.2, p.82); cf. Calvin, Inst.4.17.18. The only instance I have been able to find in the literature where members of the church are explicitly said to be enhypostatized in Christ is V. Lossky, op.cit., p.165.

17. See e.g. K.Rahner, Studies in Modern Theology (pp.16ff) on the relationship of human and divine authorship in the Bible.

18. See above, ch.9, fn.100.

19. e.g. Cyprian, De Unit.Eccles.14.

20. On the significance of 'hearing the word' and 'receiving the sacraments' worthily see below, section 3.

21. Ambrose, Enar.in Ps.38.25; Augustine, In Johan.80.3.

22. Calvin, Inst.4.14.3,5; on the dialectic of 'revelation-in-word' and 'revelation-in-reality' see E.Schillebeeckx, Revelation and Theology, London, 1976, pp.9,18, 39.

23. See above, p.320.

24. Cyril of Jerusalem, Cat.3.3f.

25. Basil, De Spir.Sanct.35.

26. E.Schillebeeckx, The Eucharist, London, 1968, pp.55f, 72ff.

27. ibid, p.69.

28. See E.Plass, ed., op.cit., p.797, no.2478.

29. ibid, p.805, no.2495, and p.806, no.2497.

30. Calvin, Inst.4.17.17,29.

31. Calvin imagined that, while we feed on the bread and wine, Christ radiates his power into our souls like a sun shining on us from heaven (Inst.4.17.10,24), an image later taken up by Bobert Bruce in his 1589 sermons (The

<u>Mystery of the Lord's Supper</u>, London, 1958, p.92). Bruce used the term 'sacramental conjunction' to describe the relation between Christ's body and the sacrament (<u>ibid</u>, pp.44,52).

32. See A.J.Heschel, <u>The Prophets</u>, p.326.

33. See above, pp.104ff.

34. I take 'ecstasy' here to mean an extension of subjecthood beyond the confines of the body, not a separation of the soul from the body as in A.J.Heschel, <u>loc.cit</u>. Furthermore, I do not regard 'enthusiasm' as a displacement of man's soul (i.e. normal mental faculties) by God, but rather as a state of complementarity between man (body and soul) and God. Therefore, whereas for Heschel (<u>op.cit</u>., p.327) 'ecstasy' (on his terms a loss of consciousness or departure of the soul) is a prerequisite for 'enthusiasm', in our view just the opposite is true as will be shown.

35. Augustine, <u>In Johan</u>.6.15,53.10,62.1; Aquinas, <u>Sum.Theol</u>. 3.76.8; Luther (see E.Plass, ed., <u>op.cit</u>., p.818, no. 2536); Calvin, <u>Inst</u>.4.15.15,4.17.33.

36. Calvin, <u>Inst</u>.4.14.5,4.15.14,4.17.18,36.

37. E.Schillebeeckx, <u>The Eucharist</u>, pp.108f, 130ff.

38. The hierarchical structure here is exactly the same as in the case of the church or that of the general relation between heaven and earth in relation to man, body and soul (see p.306 above).

39. "The community is therefore not only the receiver of the Word of revelation; it is itself revelation and Word of God. Only in so far as it is itself the Word of God can it understand the Word of God." Bonhoeffer, <u>Christology</u>, p.60.

40. See above, pp.24f (in regard to atomic physics) and pp. 240f (in regard to theology).

Chapter 12

Conclusions and Suggestions for Future Research

12.1 Conclusions:

The conclusions we have reached in this study may be restated and summarized as follows: (1) Bohr's ideas form a coherent body of 'logic' which is worthy of consideration in its own right.

(2) The epistemological basis of Bohr's thought is the criterion of <u>communicability</u> or <u>intersubjectivity</u> which requires that all objective knowledge be expressed in the terms of ordinary language and logic. When applied to 'extra-ordinary' fields like quantum mechanics, this criterion leads to the <u>correspondence principle</u>: all results must be expressed in terms of classical physics even when they transcend the classical framework and call it into question. When classical concepts are applied in this way they are semantically displaced, so there is an incommensurability as well as a correspondence between the classical and applied senses of the terms.

(3) When classical concepts are applied to atomic objects they must be subjected to a principle of <u>complementarity</u>. Complementarity is basically an ontological principle; it concerns the 'modes of being' of atomic objects (i.e. the 'wave-mode' and the 'particle-mode'). But being is viewed relationally here; the mode of being is determined by the context or environment of the object, and when an observation is being made by a scientist the experimental

apparatus is that environment. Hence, complementarity has an epistemological correlate, the dialectic of 'application' and 'analysis', or (to use Polanyi's terms) 'tacit' and 'specifiable' knowledge. When the object is being analyzed, it is located on the object-side of the subject-object boundary and is known specifiably, but, when it is applied in accordance with its proper function, it is indwelt on the subject-side of the boundary and is known tacitly. However, the location of the subject-object boundary is an empirical feature of the experimental arrangement; it is not just a function of the mental attitude of the human observer. Hence, complementarity, in Bohr's sense, is not a relationship between different viewpoints (Born), or between alternative frameworks of description (Wheeler and Feynman), or between phenomena and noumena (Heisenberg and von Weizsäcker).

(4) Complementarity can also be applied to the relationship of atom and organism in biology and to the relationship of mind and body in psychology. Hence, there is a <u>structural parallel</u> or <u>homology</u> between the uses of complementarity in the various sciences. Moreover, these applications are <u>related hierarchically</u> and there is an <u>overall progression</u> or <u>semantic displacement</u> in the significance of complementarity from one end of the hierarchy to the other. For example, there is a progressive emergence of correlation between the states of alternate modes at the biological level and an emergence of internalization and individuality at the psychological level of the hierarchy. These adaptations do not affect the formal definition of complementarity, but they serve to dislodge it from the peculiar context and

connotations of atomic physics.

(5) In psychology, complementarity can also be applied to the modes of the existence of ideas in man's mind (epistemological complementarity). The application or indwelling of the concept of an object is the mental complement of the application or indwelling of the object itself. Hence, man's ability to think, to create and manipulate ideas in his mind, is complemented by his ability to extend the boundary of his subjecthood beyond the natural limits of his body, to indwell external objects, and to fill the subject-side of the subject-object boundary. The ontological (mind-body) and epistemological (analysis-application) aspects of complementarity are here seen to be orthogonal to each other.

(6) The notion that personal involvement or subjecthood plays a positive role in human knowledge is not a new one. Dilthey's concept of <u>Verstehen</u>, contrasted with <u>Erklären</u>, and Collingwood's concept of the 'understanding' of thoughts, contrasted with the 'perception' of physical events[1] may be cited for comparison. The novel features of Bohr's view are: (a) It applies to all the sciences and so unifies them hierarchically rather than dividing them into two opposing types such as the 'natural' and 'spiritual' sciences of Dilthey.[2] In this sense, it is more like Tillich's concept of 'receiving', as opposed to 'controlling', knowledge,[3] or Polanyi's concept of 'tacit', as opposed to 'specifiable', knowledge.[4] (b) The epistemological complementarity of analysis and application is grounded in the ontological complementarity of structure and function; the

analysis of an object is the (specifiable) knowledge of its structure (at a given level) while the application of the the same object is the (tacit) knowledge of its function. Hence, the effect of personal involvement is not to isolate the subject in a world of his own, but to bring him into real contact with the external world.

(7) In the field of theology, complementarity may be applied to a number of doctrines that involve a polarity of 'modes' or 'natures'. Seen as a whole this group of theological doctrines extends the hierarchy of complementarities beyond the level of man to God. The overall hierarchy is monotonic in the sense that the direction of 'revelation' or 'pointing' is always upward, but this basic symmetry is broken by a reversal in the direction of ontological dependence at the level of man; levels below (and including) man depend on lower levels while those above man depend on yet higher ones. One result of this curious reversal is the fact that the relational view of being (and attributes) does not apply to God. God has no environment, and his modality is purely spontaneous or or active; it is not a response to changes in the 'experimental arrangement' as is that of atoms and organisms. In short, all being is <u>modal</u>, but only contingent being is <u>relational</u>.

(8) Our application of complementarity to Christian theology has led us to make several assumptions or conditions. One such condition is that the three orderings or dimensions of the 'generation' of the Son (and/or the 'procession' of the Spirit, in short, the <u>opera ad intra</u>), the transcendence and immanence of God with respect to the world

(the <u>opera ad extra</u>), and time must be regarded as orthogonal to each other. Hence, the preexistent Logos (Son) is strictly distinguished from the creative immanence of God in the world. This assumption is not necessary for the application of complementarity as such, but it is required by the demands of Christian orthodoxy.[5]

(9) Another condition is that God and time be regarded as two distinct realities that interpenetrate in an asymmetrical fashion. In complementarist terms, there are three 'modes' composing two 'realities'; God exists in two modes, 'transcendent' and 'immanent', and time also exists in two modes: one is creation itself, and the other is the immanent Godhead. Thus the immanent Godhead acts as a middle term; it belongs to both realities. In other words, God <u>is</u> complementary to creation (due to his immanence), but he is not <u>just</u> the complement of creation (due to his transcendence). God and the world are <u>one</u> being, but God himself is a <u>distinct</u> (though not an other) being. It follows that God is the ground of <u>all</u> being. Again, this is not a new result; the novel feature is the mode of derivation.

(10) The application of complementarity to the relation of (immanent) God and the world, or of Creator and creature, requires a 'relational', as opposed to an 'instrumental' view of time. Our common-sense notion of time is based on the measurement of creaturely events with physical clocks, and it is impossible on this basis to determine whether the acts of God are simultaneous with those of the creature or whether divine acts precede the corresponding

creaturely ones. Yet the application of complementarity would require such a precedence, not just in the logical, but in the temporal sense if God's immanence is to be taken seriously at this point. Hence complementarity would require an expansion or generalization of our common-sense notion of time to allow for divine, as well as creaturely, moments. Time must be defined in relation to the alternate, corresponding acts of Creator and creature, not the other way around.

(11) The concepts of a created heaven and of angels are no more (or less) mythological than those of mind and of God. The relationship of heaven and earth and the phenomenon of 'theophany' can be understood in terms of complementarity. In this context, it makes sense to speak of Christ's 'coming down' from heaven and 'ascending' to heaven again after the resurrection.

(12) The hierarchy of theological concepts is multi-levelled (God-heaven-earth) just as the hierarchy of the sciences is (atom-organism-man). Hence, the popular distinction of 'matter' (all physical objects including man's body) and 'spirit' (including man's soul, the angels and God) is misleading on several counts: (a) it is oversimplified; there are many levels, not just two, (b) it suggests an arbitrary dichotomy in the realm of being; one of the two sides is bound to be regarded as more real then the other, (c) it treats God as one (spiritual) being among many on the same level, and (d) it tends to be interpreted as a relationship between 'phenomena' and 'noumena' or between the realms of the 'sensible' (<u>kosmos aisthetos</u>) and the 'intelligible'

(*kosmos noetos*).[6]

(13) All of the theological doctrines we have considered have a common element which was not forseen in the logic of complementarity as derived from the sciences. In the doctrine of the Trinity there is the derivation of the properties of the Son from the Father (the *enousios*); in the doctrine of creation there is the fact that God is the 'ground' of all being: in Christology there is the *enhypostasia*; and in the doctrine of the sacraments there is the notion of 'transubstantiation'. In the language of complementarity this means that all properties that are common to to the two modes have their source in the ontologically prior mode. There is no logical reason why the same could not be said in the sciences; for instance, it could be said that a stable atom (wave-mode) derives its rest mass and net electrostatic charge from its constituent particles. Hence, there are not two 'masses' (or two 'charges'), one of the atom as a whole and the other of the constituent particles, but one mass, that of the particles which is the source of the derived 'mass' of the stable atom. Such metaphysical language might sound strange to a physicist, but it would no more suggest the unreality or incompleteness of the wave-mode of atoms than the *enhypostasia* implies the unreality or incompleteness of the humanity of Christ.

(14) Complementarity is basically a *synchronic* principle; it applies to the ongoing dialectic or relationship between two alternate modes of being. It may be said to 'generate' time, as in (10) above, but it tells us nothing about where time is 'going'; it says nothing at all about

history. From the viewpoint of complementarity alone, there is no essential difference between the relation of Creator and creature in providence, theophany, and incarnation (the unio personalis). All three of these doctrines involve the same two levels of the complementarist hierarchy, so their distinction requires a diachronic principle which complementarity allows for but does not actually provide. For instance, the uniqueness of Christ consists in the intensity and permanence of God's (or God-the-Son's) involvement in the humanity of Jesus, but this permanance is only effected 'retroactively' from the standpoint of the resurrection.[7] Therefore, it is historically constituted and cannot be understood in terms of complementarity, or any other synchronic principle, alone. The distinction here between synchronic and diachronic corresponds to that between 'revelation' (from 'above'; Barth, Brunner) and 'revelation history' (Cullmann, Pannenberg). In our view, both are required to do full justice to the complex structure of Christian theology.

(15) Finally, it should be noted that our application of complementarity to theology takes no account of the problem of evil. For one thing, the existence of evil can only be discussed properly in the language of history, for example, in terms of a primeval 'fall', or else of an eschatological goal.[8] The fact that evil has no place in the complementarist hierarchy simply reflects the more basic fact that it has no being of its own, not even the relative, contingent being of creation.[9] Hence it cannot be understood in terms of 'modes of being'.

12.2 Suggestions for Future Research:

A number of interesting questions have been raised in the course of our study, and it may be worthwhile listing some of these for future reference.

(1) The hypothesis that living organisms exist in a supra-atomic mode does not prevent them from being photographed continuously, as in a high-speed motion picture.[10] Apparently the photography does not disturb the interior states of the organism, but the continual interaction of the organism with light requires that its surface exist in the atomic mode at all times. Hence, there must be a kind of boundary layer or 'skin' between the interior of the organism and the external environment. The 'interior' would still alternate between atomic and organismic modes,[11] and information would be exchanged between 'skin' and 'interior' during the brief intervals in which the latter exists in its atomic mode. The 'skin' must include the outer layers of molecules, so its thickness must be at least a hundred Angstrom units (10^{-6} cm). In physiological terms it coincides with the exposed surfaces of the sense organs, e.g. the retina of the eye and the surface of the tongue, where information is continually received from the environment at the physico-chemical level. It may also include the involuted surfaces of the respiratory and digestive systems where nutrient material is continually being absorbed at the chemical level.[12] Hence the application of complementarity to biology could be developed into a multi-levelled model of the interaction of an organism with its total environment.

(2) The hierarchy of complementarities in the

sciences also involves a hierarchy of time scales. At the atomic level, wave-particle alternations require only 10^{-8} seconds, while, at the other end of the hierarchy, the mind-body alternation requires at least a tenth of a second.[13] In between these two extremes there are a number of organismic and mental levels with intermediate time scales. The implication is that for every single alternation at one level there are a number of alternations at the next lower level. In other words, a number of alternations (perhaps ten) between the modes at the lower level are needed to establish the state of the lower mode at the next higher level. A number of alternations between the modes at this second level are in turn needed to establish the state of the lower mode on a third level, and so on. Consequently, in order for information to be passed from lower to higher levels there must be some kind of information storage or 'short-term memory'[14] at each of the intermediate levels. The information contained in one of the first of a series of mode-events at one level must not be lost before the series is completed and the information can be passed on to the next higher level. Furthermore, there must be a 'threshold' mechanism at each level. If a particular stimulus affects the state of only one or two in a series of mode-events at one level, the information may not be passed on to the next higher level. Only if the number of excited mode-states exceeds some threshold value (which may depend on the intensity of the stimulus)[15] will the information be passed on and become a stimulus for the next higher level. Here we have the makings of a fairly detailed model for the process of perception which could perhaps be elaborated and tested empirically.

(3) The highest psychic processes that are investigated in conventional cognitive psychology are the conception of words (verbal responses to physical stimuli) and the perception of visual forms, both of which involve time scales of a fraction of a second.[16] However, there is also a growing interest in the psychology of meditative states which may last for many seconds or even minutes.[17] It is possible that these 'higher' psychic processes could be understood as an extension of the complementarist hierarchy described above.[18] In this case, one would expect that the degree of 'ecstasy' (which can be determined empirically)[19] would be correlated with the time required for the establishment of the corresponding meditative state. In other words, the more intense ecstatic experiences would involve higher levels of mind and so would require longer time scales.

(4) The association of meditative states with the 'unconscious' is frequently taken to imply that they are purely subjective. In extreme cases of ecstasy it may be true that "I-Self communication" breaks down and the individual is cut off from the external world in a state of "pure self-reference".[20] However, there are also intermediate states in which conscious and unconscious forces are counterbalanced and the individual is able to function in the external world with great skill.[21] Could there be a connection between this reality-oriented 'ecstasy', this 'standing out' of oneself, and Michael Polanyi's concept of "dwelling in' the object of one's attention?[22] If so, then there

might be grounds for interpreting some forms of mystical experience as the tacit perception of higher modes of being in the external world.

(5) In our discussion of complementarity in biology and psychology we noted that there is an increasing degree of 'correlation' between the states of alternate modes at higher levels of being.[23] Ultimately, the correlation becomes complete at the level of God's concurrence with creaturely events.[24] In fact, the various degrees of correlation at creaturely levels are upheld by the perfect correlation of providence. But what is the precise nature of this 'correlation'? If it were simply mechanical or deterministic, the relative independence of the various modes and levels of being would be threatened. When we speak of the conformity of creaturely activity to the will of God we use terms like 'providence' and 'grace'. For the translation of atomic stimuli into organismic states and mental ideas we use the term 'perception'. Should we be embarassed by the seeming vagueness of these terms and seek for an 'explanation' in more conceptual categories, or should we regard them as inherently irreducible and hence perfectly legitimate in their appropriate contexts?

(6) In this study we have stressed the vertical, hierarchical structure of being, and we have developed a particular model for this structure based on Bohr's principle of complementarity. It might also be possible to develop a model for the horizontal dimension of history based on the correspondence principle.[25] There is a relationship of 'correspondence' and 'incommensurability' between type and

antitype or promise and fulfillment just as there is between the classical sense of a concept and the meaning it receives when applied to a new branch of science.[26] This dialectic of correspondence could be applied quite generally to the relationship between any two events in a single continuous history; the earlier event has significance in itself, but it takes on new significance in the light of the subsequent event. For example, the crucifixion has one significance in itself and quite another in the light of the resurrection.[27] The 'retroactive effect' of events on previous history is then analogous to the semantic displacement brought about by the application of classical concepts to new situations. If such a model of history were to replace the notion of events as atomized beads on a string, some of the difficulties that plague current philosophies of time might well be avoided.

(7) Throughout this study we have been equating 'theology' with 'Christian theology'. Christian theology is particularly suited to a complementarist analysis because it abounds with dipolar concepts like the intra-personal relations in the Trinity and the two natures of Christ. But similar concepts occur in other religious traditions. For instance, there is the relation between Brahman and Ishvara, or <u>nirguna</u> Brahman and <u>saguna</u> Brahman, in Vedanta, or the <u>trikaya</u> (three bodies of the Buddha) doctrine in Mahayana Buddhism.[28] How would complementarity work as a model in such cases? Unfortunately, there is a reluctance in Eastern traditions to specify the exact relations in question with the degree of precision required for such an investigation. Moreover, there is a strong tendency to regard the lower

modes or levels as being less real than the higher ones.[29] Would factors like these rule out the application of complementarity to Eastern traditions? If so, what is the significance of the fact that the Judeo-Christian tradition is <u>uniquely</u> susceptible to complementarist analysis? Does it merely reflect the common Western background of Christian theology and modern science, or does it actually tell us something about objective reality?

(8) What, then, is the significance of the fact that a complementarist analysis applies to God as well as to man and nature? Does this simply reflect a category of perception in the sense that anything man (i.e. Western man) perceives is automatically cast into the mold of complementary modes of being? The answer to this question hinges on one's view of the correspondence principle. Granted the viability of classical language in non-classical fields of experience, the appearance of complementary modes is to be expected.[30] But without a belief in the fundamental propriety of classical concepts, the objectivity not only of complementarity but of every ontological assertion is subject to doubt.[31] From the theological viewpoint, therefore, the concept of complementarity has two important implications:

The logic with which God has endowed creation is fundamentally the same as that with which he himself is imbued. God exists eternally in complementary modes of being, and he upholds his creation is such a way that it too participates in the logic of complementarity; ultimately it participates in complementarity with God himself. If this were not the case, we may speculate, man's knowledge of God would be completely unlike his knowledge in other fields, and theology would be totally discontinuous with the other sciences. A belief in the objective validity of complementarity, therefore, entails a belief in the grace of God in creation which allows an underlying continuity between creation and revelation.

But unless man's fundamental concepts, like wave and particle or father and son, have a certain legitimacy even in areas that are far removed from everyday human experience, the foundations of every science, whether natural or theological, would forever be uncertain. Therefore, the belief in the objective validity of complementarity also entails a belief in the providential quality of human society and the ordinary human concepts which are socially maintained.[32] One cannot argue from the basic validity of human concepts to the nature of God without presupposing the grace of God in the formation of those very concepts in the first place.

12.3 Evaluation:

Throughout this study I have been trying to demonstrate the viability of complementarity as a conceptual tool in the sciences and in theology. However, a number of serious difficulties have arisen and these should not be forgotten in our final evaluation.

First, it should be noted that there are basic ambiguities in the definition of complementarity itself. Concepts like 'unity of being', 'coinherence', and 'pointing' can be defined with reasonable precision in the context of Bohr's writings, but when they are lifted out of the context of atomic physics and applied to other areas they tend to become abstract and rather elastic. These ambiguities become particularly troublesome in the application to theology where very fine distinctions are required.

For instance, under the rubric of 'unity of being' we have considered such diverse topics as the consubstantial unity of persons in the Trinity, the ontological solidarity of God and the world in creation and providence, the hypostatic union of human and divine natures in Christ, and the mystical union of Christ and the church.[33] Clearly, such an enormous feat of assimilation is only made possible by the suppression of the peculiar features, ontological and historical, which make each one of these relations unique. In other words, the application of complementarity to theology transforms the concrete, intuitive ideas of Bohr into abstract, formal principles which Bohr would hardly have recognized or appreciated himself.

Moreover, we have found that the application of complementarity to several theological doctrines becomes feasible only when special models are artificially constructed. For example, the intra-trinitarian relations must be treated dyadically in such a way that the Father-Son relation can be dissected from the Spirator-Spirit relation. It is true that the full complexity of the Trinity can be reconstructed from these separate relations, but one might well question whether the procedure of analysis and synthesis is at all appropriate in this context. Here again, the principle of complementarity would seem to have been transformed into something quite different from what its author intended it to be.

Similarly, the application of complementarity to the God-world relation requires an analysis into two distinct relations; that between the essence and the energies of God, and that between the immanent energies of God and the world. The most that could be said here is that the relation of Creator and creature has always seemed to defy logical analysis and that <u>any</u> specific model is bound to be strained to the limit.

Finally, the application of complementarity to theophany and Incarnation requires a strict distinction between historical and structural features. From an analytical viewpoint, it makes sense to posit two orthogonal dimensions, diachronic and synchronic, and this procedure is accepted in disciplines like linguistics and sociology. But it becomes somewhat artificial in the context of Christian theology where history enters into the very structure of being as in the Incarnation.

In all his writings, Bohr was reacting <u>against</u> the emphasis of contemporary science on formalism and analysis, and he conceived the principle of complementarity in the hope that it would <u>counteract</u> these tendencies. However admirably it may succeed in the context of quantum theory, or even biology, we are forced to conclude that it does not do justice to the concreteness and the integrity of the God who has revealed himself in Jesus of Nazareth. Perhaps this negative result would not have disappointed Bohr at all for he "vividly realized that our proud theories are but temporary resting places of the mind on the unending road to knowledge."[34]

Then, recognizing the full limitations of complementarity in the theological field, what may we say are its legitimate functions? First, the terms 'complement' and 'complementary' may prove to be useful and enriching in theological discourse. It could be said, for instance, that the Son is the full 'complement' of the Father or that divine sovereignty and human freedom are 'complementary' causes of a particular event. At the outset, some basic rules would have to be established to prevent misunderstanding. For example, it would have to be stressed time and time again that complementarity is not a symmetrical concept so that it would not suggest reversibility. Moreover, one would have to be reminded that complementarity is a strictly contextual concept: God and the world are 'complementary' only within the context of creation and providence; the Word and the flesh are 'complementary' only within the *unio personalis*, and so on. But all of these difficulties arose with the first use of the term *perichoresis*, as well, so one may expect that the appropriate sense of 'complementarity' would gradually be established through usage and adaptation.

Secondly, the eleven-point definition of complementarity (or some improved version) could be used as a format for the exposition of various theological doctrines as we have shown. The functions of such a format would be heuristic and pedagogical. On the one hand, it could be used to demonstrate common themes, like the derivation of common properties from the ontologically prior mode, and, on the other, it would serve to pinpoint difficulties in terminology and problems of conceptualization, such as the description of supra-temporal orderings in ostensibly temporal language. Again, however, the contextual nature of the eleven points would have to be stressed. The claim is not that point 'n' in doctrine 'A' is _the same_ as point 'n' in doctrine 'B', but that point 'n' stands in _the same relation_ to the other ten points in one doctrine as it does in the other. For instance, the coinherence of Father and Son plays the same role in the Father-Son relation as a whole as the interpenetration of Word and flesh does in the context of the _unio personalis_, and both of these function, in their respective contexts, in the same way that the coinherence of wave and particle does in atomic physics. The analogy is one of proportionality, not of direct proportion.

Finally, _the hierarchy of complementarities_ could be used to investigate the complex relationships between theological doctrines. In spite of the dangers of analysis and formalism, some useful insights could be readily established. For instance, the doctrines we have studied fall into two basic groupings: The doctrine of the Trinity and the relation of essence and energies owe their uniqueness primarily to their location within the overall hierarchy, or rather their location above and beyond the hierarchy of temporal complementarities. In contrast, the doctrines of providence, theophany, and Incarnation cannot be distinguished on hierarchical grounds alone; here the role of historical relationships becomes all-important. While complementarity cannot give a definitive treatment of these complex issues, it does serve to bring them out into the open so that the relevant discussions in the theological literature can be better appreciated.

Ultimately, the success of complementarity as a fundamental principle depends on what one expects of it. As a conceptual tool borrowed from the sciences it may well be of service in theological discourse. Like any other concept, it must be adapted through usage. However, it could never become an over-arching master concept for it could never do full justice to the God who reveals himself as Lord.

Footnotes: Chapter 12

1. R.G.Collingwood, The Idea of History, London, 1961, esp. pp.213-216.

2. W.Dilthey, Einleitung in die Geisteswissenschaften, Leipzig-Berlin, 1923, pp.32-33.

3. P.Tillich, Systematic Theology, Volume 1, London, 1953, pp.108ff,114f.

4. M.Polanyi, The Study of Man, Chicago, 1958, pp.72f, Knowing and Being, London, 1969, pp.155f,160.

5. See above, p.247.

6. T.F.Torrance, Space, Time and Incarnation, London, 1969, ch.1.

7. W.Pannenberg, Jesus - God and Man, London, 1968, pp.321f.

8. John Hick refers to these alternatives as the "Augustinian" and "Irenaean" types of theodicy; Evil and the God of Love, London, 1968.

9. cf. K.Barth, Church Dogmatics III.3, ch.50.

10. See M.Rosthschild et al., "The Flying Leap of the Flea", Sci.Am. 229(No.5), 1973, pp.92-100, where pictures were taken at a rate of 3500 frames a second.

11. See above, chapter 3, fn.52.

12. As Bohr pointed out, the continual exchange of atomic matter between organism and environment makes it impossible to define the boundary of the organism at the atomic level; see above, pp.93f.

13. See above, chapter 3, fn.83.

14. e.g. "iconic memory", see U.Neisser, Cognitive Psychology, New York, 1967, pp.18-22.

15. On the "perfect summation" of visual energy (=intensity x duration of stimilus), see ibid, pp.21f.

16. ibid, pp.36ff,138ff.

17. M.Laski, Ecstasy, London, 1961, ch.5.

18. cf. R.E.Ornstein, The Psychology of Consciousness, San Francisco, 1972.

19. R.Fischer, "A Cartography of the Ecstatic and Meditative States", Science 174, 1971, pp.897-904, and "Time: A

Biocybernetic and Psychopharmacological Approach", in J.Zeman, ed., Time in Science and Philosophy, Prague, 1971, pp.165-178.

20. R.Fischer, op.cit. pp.901f and 173f, respectively. The "I" represents the normal, everyday self in contact with the external world (cf. Freud's 'Ego'). The "Self" represents the inner depths of the 'unconscious' Freud's 'id').

21. e.g. the role of meditation in the Zen arts of archery and swordsmanship; see E.Herrigel, Zen in the Art of Archery, New York, 1953; and D.T.Suzuki, Zen and Japanese Culture, Princeton, 1959, pp.94-108. Compare Jung's concept of the creative 'Self'; see R.Wilhelm and C.J. Jung, The Secret of the Golden Flower, London, 1962, pp. 124,132.

22. In Personal Knowledge, (London, 1958, pp.61f) Polanyi virtually equates tacit knowledge with unconscious awareness, but in Knowing and Being (London, 1969, p.194) he states that "it would be a mistake to identify subsidiary awareness with subconscious or pre-conscious awareness or with the fringe of consciousness described by William James."

23. See above, pp.107f.

24. See above, pp.281f.

25. See above, chapter 9, fn.5.

26. J.McIntyre, The Christian Doctrine of History, Edinburgh, 1957, pp.70-76; B.S.Childs, Myth and Reality in the Old Testament, London, 1962, pp.77-84; G.von Rad, Old Testament Theology, Volume 2, London, 1965, pp.363f; W.Pannenberg, Basic Questions in Theology, Volume 3, London, 1973, pp.58-66.

27. See above, pp.294f.

28. See H.W.Schumann, Buddhism, London, 1973, pp.101-109; cf. the "three forms of Brahman" in Vallabha's Suddhadvaita Vedanta (see S.Radhakrishnan's "Introduction" to the Brahma Sutra, London, 1960, p.89) and the corresponding "three forms of the goddess" (W.C.Beane, "The Cosmological Structure of Mythical Time: Kali-Śakti", History of Religions 13, 1973, p.56. The corresponding "three forms" in Christian theology would be transcendent God, immanent God, and the created world; see above, pp.271f.

29. cf. R.Brooks, "The Meaning of 'Real' in Advaita Vedanta", Philosophy East and West 19, 1969, pp.385-398. Some possible exceptions would be Visishtadvaita and Dvaitadvaita Vedanta.

30. See above, pp.19ff.

31. See above, pp.141f.

32. See above, p.18; cf. M.Polanyi, Science, Faith and Society, Chicago, 1964, pp.83f.

33. Barth has effectively criticized these analogies in Church Dogmatics, IV.2, pp.52-60.

34. L.Rosenfeld, "Niels Bohr's Contribution to Epistemology", Physics Today 16 (No.10), 1963, p.49.

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